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THIRD SURVEY OF

DRY SO_2 CONTROL SYSTEMS

by

Mary E. Kelly and S.A. Shareef

Radian Corporation
3024 Pickett Road
Durham, North Carolina 27705

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Project Officer

Theodore G. Brna

Utilities and Industrial Power Division
Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711

Prepared for

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16. ABSTRACT The report is the third on the status of dry flue gas desulfurization (FGD) processes in the U.S. It reviews current and recently completed research, development, and commercial activities. Dry FGD systems covered include: (1) spray dryers with a fabric filter or an electrostatic precipitator (ESP), (2) dry injection of alkaline material into flue gas, combined with particulate collection in an ESP or a fabric filter, and (3) combustion of coal/alkali fuel mixtures. Spray drying remains the only commercially applied FGD process. With two new utility and two new industrial spray drying system sales since the last report, dry FGD has been selected for 3600 MW of utility generating capacity and about 600,000 acfm of industrial coal-fired flue gas. All new systems use a lime sorbent and a fabric filter for particulate collection. No new commercial systems have begun operation since the Fall of 1980, but the first utility system was scheduled to start up in the Spring of 1981. Pilot-scale demonstration programs which have been recently completed and several continuing programs are discussed. Significant work on dry FGD waste disposal has begun under both government and industry sponsorship and is addressed in the report.

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Sulfur Oxides	Electrostatic Precipitators	Stationary Sources	07B	
Flue Gases		Dry Processes	21B	13I
Desulfurization	Alkalies	Fabric Filters	07A,07D	
Filtration				
Fabrics			11E	

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ABSTRACT

This report is the third in a series of reports on the status of dry flue gas desulfurization (FGD) processes in the United States.* This updated assessment of dry FGD systems is based on review of current and recently completed research, development, and commercial activities. Dry FGD systems covered include: (1) spray dryers with a fabric filter or an electrostatic precipitator (ESP), (2) dry injection of alkaline material into flue gas combined with particulate collection in an ESP or a fabric filter, and (3) combustion of coal/alkali fuel mixtures.

Spray drying continues to be the only commercially applied FGD process. Since the last survey was completed in the Fall of 1980, two new utility and two new industrial spray drying systems have been sold. All of these new systems use a lime sorbent and include a fabric filter for particulate collection. No new commercial systems have come on line since the last survey report but the first utility system is scheduled to start-up in the Spring of 1981.

A number of pilot-scale demonstration programs funded by vendors, utilities, and/or government agencies have been completed in the last few months and several similar programs are continuing currently. The Environmental Protection Agency is currently funding a spray drying demonstration program and a program for the development of a process for combustion of coal/limestone fuel pellets. In a program jointly funded by the EPA and the Department of Energy, the combustion of a pulverized coal/alkali fuel mixture in a low-NO_x burner is being investigated. The Department of Energy and a few vendors, as well as EPA, are continuing to investigate dry injection through pilot-scale demonstration programs. In addition, a substantial amount of work has begun in the area of dry FGD waste disposal. Waste disposal projects are being funded by the DOE, the Electric Power Research Institute (EPRI), and several vendors.

*Previous report numbers EPA-600/7-80-030 and EPA-600/7-81-018. (Available through National Technical Information Service).

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SECTION 1

INTRODUCTION

This report is the third in a series of reports on the status of dry flue gas desulfurization (FGD) processes in the United States for both utility and industrial applications. Throughout this report, dry FGD will be defined as any process which involves contacting a sulfur-containing flue gas with an alkaline material and which results in a dry waste product for disposal. This includes (1) systems which use spray dryers for a contactor with subsequent baghouse or electrostatic precipitator (ESP) collection of waste products; (2) systems which involve dry injection of alkaline material into the flue gas with subsequent baghouse or ESP collection; and (3) other varied dry systems which are primarily concepts that involve addition of alkaline material to a fuel prior to combustion. This definition of dry systems excludes several dry adsorption or "acceptance" processes, such as the Shell/UOP copper oxide process and the Bergbau-Forschung adsorptive char process since the status of these processes has been documented in previous EPA reports. Fluidized bed combustion has also been excluded.

Also excluded was the regenerable Rockwell Aqueous Carbonate Process (ACP) which, although based on SO_2 removal with a spray dryer, does not fit the limitation of this study as being a "throwaway" system. However, the open loop, spray dryer contactor portion of the Rockwell process has been adapted for a "throwaway" system and, as such, has been included here.

1.1 REPORT ORGANIZATION

Section 2 presents an overview of the major types of dry FGD processes considered in this survey and includes:

1) A summary of new developments in the dry FGD area.

2) A discussion of the recent commercial and developmental activities for each type of process (spray drying, dry injection, and combustion of a coal/limestone fuel mixture).

Section 3 presents detailed descriptions of current and recently completed dry FGD research and development programs, and commercial sales summaries. Finally, Section 4 provides information on the physical and chemical characteristics of dry FGD wastes, current and planned disposal methods for commercial units, on-going waste disposal studies, and recently developed schemes for utilization of the waste solids.

1.2 TYPES OF DRY FGD SYSTEMS

This section provides a general process description for each of the three technologies being considered (i.e., spray drying, dry injection, and combustion of coal/alkali fuel mixtures). This background information is provided for the reader who may be unfamiliar with the technologies and is only intended to be a generalized description of the system.

1.2.1 Spray Dryer Systems

In these systems, flue gas at air preheater outlet temperatures (generally 250 to 400°F) is contacted with a solution or slurry of alkaline material in a vessel of 5 to 10 seconds gas residence time. Sodium carbonate and lime are the most widely used sorbents for spray drying. Sodium, being more water soluble, is more reactive. This increased solubility can, however, lead to waste disposal problems as discussed later in this report. The flue gas is adiabatically humidified to within 20 to 50°F of its saturation temperature by the water evaporated from the solution or slurry. As the slurry or solution is evaporated, liquid phase salts are precipitated and remaining solids are dried to generally less than one percent free moisture. These solids, along with fly ash, are entrained in the flue gas and carried out of the dryer to a particulate collection device. Reaction between the alkaline material and flue gas SO_2 proceeds both during and following the drying process.

Using a spray dryer for a flue gas contactor involves adiabatically humidifying the flue gas to within some specified degrees above saturation. With set conditions for inlet flue gas temperature and humidity and for a specified approach to saturation temperature, the amount of water which can be evaporated into the flue gas is set by energy balance considerations. Liquid-to-gas ratios are generally in the range of 0.2 to 0.3 gal/kcf. The sorbent stoichiometry is varied by raising or lowering the concentration of a solution or weight percent solids of a slurry containing this set amount of water. While holding other parameters such as temperature constant, the obvious way to increase SO_2 removal is to increase sorbent stoichiometry. However, as sorbent stoichiometry is increased to raise the level of SO_2 removal, two limiting factors are approached:

1) Sorbent utilization decreases, raising sorbent and disposal costs.

2) An upper limit is reached on the solubility of the sorbent in the solution, or on the weight percent of sorbent solids in a slurry.

There are at least two methods of circumventing these limitations. One method is to initiate sorbent recycle, either using the solids dropped out in the spray dryer or the particulate collection device catch. This has the advantage of increasing the sorbent utilization, plus it can increase the opportunity for utilization of any alkalinity in the fly ash.

The second method of avoiding the above limitations on SO_2 removal is to operate the spray dryer at a lower outlet temperature; that is, a closer approach to saturation. Operating the spray dryer outlet at a closer approach to saturation has the effect of both increasing the residence time of the liquid droplets and increasing the residual moisture level in the dried solids. As the approach to saturation is narrowed, SO_2 removal rates and sorbent utilization generally increase dramatically. Figure 1-1 shows a typical relationship between SO_2 removal and outlet temperature for a low sulfur western coal. Since the mechanisms for SO_2 removal are not clearly defined, it is not obvious whether it is the increase in liquid phase (droplet) residence time, the increase in residual moisture in the solids, or both which accounts for the increased removal.

The approach to saturation at the spray dryer outlet is set by either the requirement for a margin of safety to avoid condensation in downstream equipment or restrictions on stack temperature. The spray dryer outlet can be operated at temperatures lower than these restrictions would otherwise allow if some warm or hot gas is bypassed around the spray dryer and used to reheat the dryer outlet gas. Warm gas (downstream of the boiler air heater) can be used at no energy penalty, but the amount of untreated gas involved in reheating begins to limit overall SO_2 removal efficiencies. Significantly less hot gas (upstream of the air heater) is required to heat, but an energy penalty, associated with the decrease in energy available for air preheat, comes with using this higher temperature gas. Figure 1-2, a general flow diagram of a spray dryer-based system, illustrates these two "reheat" options.

The spray dryer design can be affected by the choice of particulate collection device. Bag collectors have an inherent advantage in that unreacted alkalinity in the collected waste on the bag surface can react with remaining SO_2 in the flue gas. Some process developers have reported SO_2 removal on bag surfaces on the order of 10 percent of total removal. Because the fabric is somewhat sensitive to wetting, a margin above saturation temperature must be maintained for bag protection. ESP collectors have not been demonstrated to achieve significant SO_2 removal. However, some vendors claim that the ESP is less sensitive to condensation and hence the spray dryer can be operated closer to saturation (about 20°F approach) resulting in increased SO_2 removal in the spray dryer.

The choice between sorbent types, (sodium- or calcium-based), use of recycle, use of warm or hot gas bypass, and types of particulate collection device tends to be rather site specific. Vendor and customer preferences, system performance requirements, and site-specific economic factors tend to dictate the system design for each individual application.

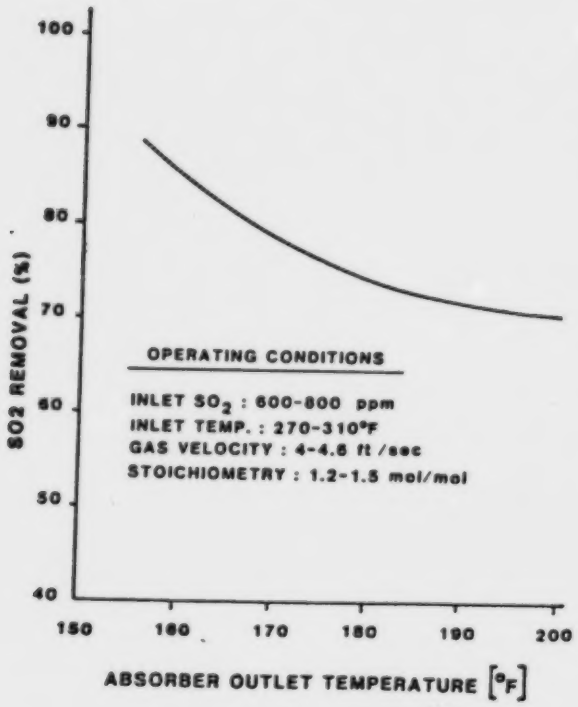

Figure 1-1. SO_2 removal for various absorber outlet temperatures.

Source: Martin, J.R. et al. "C-E Dry Scrubber Systems: Application to Western Coals". (Presented at the American Power Conference, Chicago, Illinois, April 21-23, 1980.)

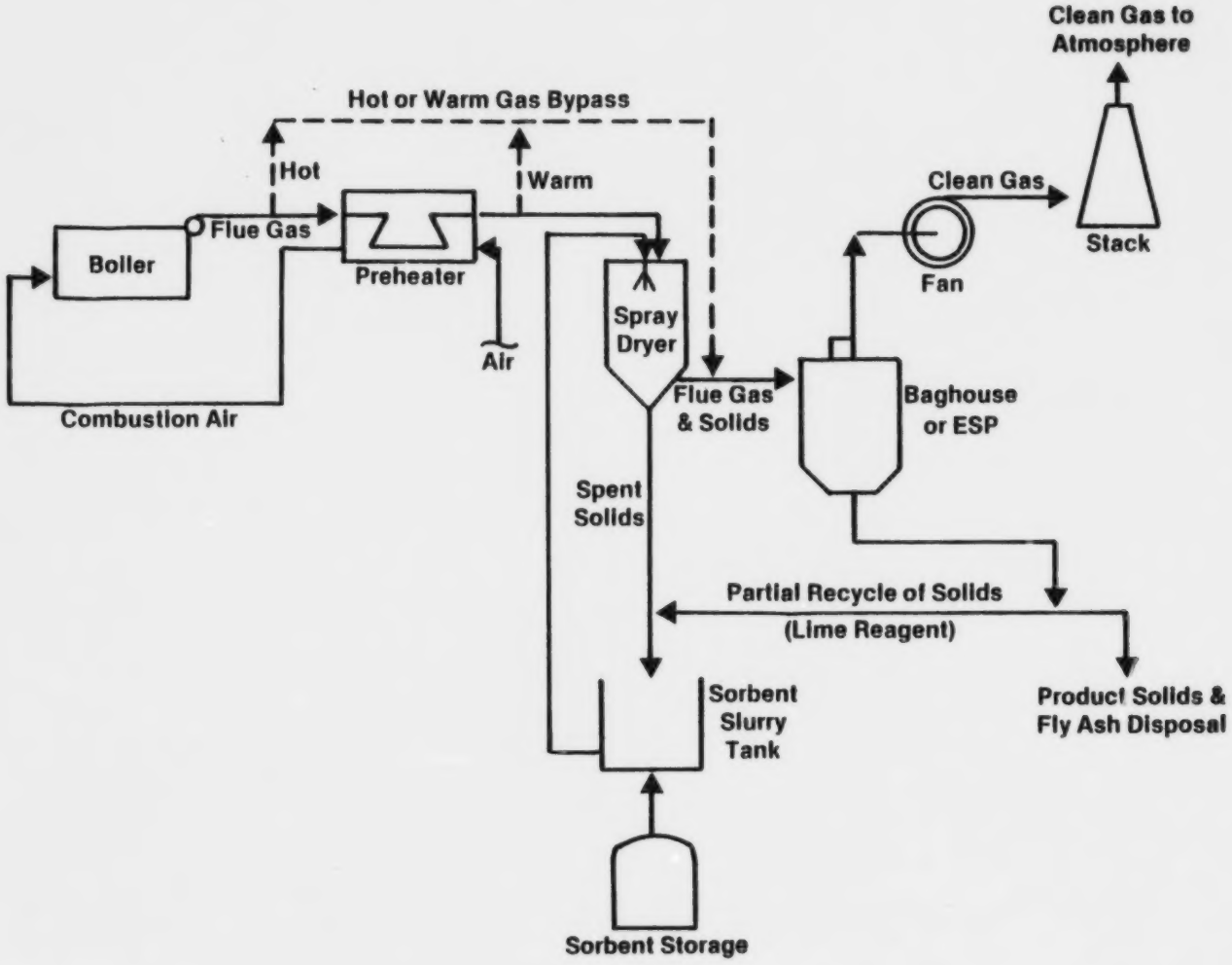

Figure 1-2. Typical Spray dryer/particulate collection flow diagram.[1]

1.2.2 Dry Injection System

Dry injection schemes generally involve pneumatically introducing a dry, powdery alkaline material into a flue gas stream with subsequent particulate collection. A generalized flow diagram of this process is shown in Figure 1-3. The injection point has been varied from the boiler furnace area all the way to the flue gas entrance to an ESP or bag collector. Most dry injection schemes use a sodium-based sorbent. Lime has been tested but has not been demonstrated with much success. Many dry injection programs have used nahcolite as a sorbent. Nahcolite is a naturally occurring mineral, usually associated with western oil shale reserves, and is about 80 percent sodium bicarbonate. Sodium bicarbonate appears to be more reactive than sodium carbonate, because it loses both two moles of CO_2 and one of water in reaction, while sodium carbonate loses only one mole of CO_2 in reaction with SO_2. The following overall reactions illustrate this point:

$$2NaHCO_3 + SO_2 \longrightarrow Na_2SO_3 + H_2O + 2CO_2 \qquad (1\text{-}1)$$

$$Na_2CO_3 + SO_2 \longrightarrow Na_2SO_3 + CO_2 \qquad (1\text{-}2)$$

Since bicarbonate loses three moles for every mole of SO_2 removal, bicarbonate particles tend to have larger pore volumes and are apparently less susceptible to blinding on reaction than are sodium carbonate particles. Unfortunately, the availability of raw nahcolite in commercial quantities in the near future is questionable due to the substantial investment necessary before commercial scale mining can begin. However, the MultiMineral Corporation is currently obtaining data for an environmental impact study and they estimate that annual production of about 1 million tons of nahcolite would be achievable in about four years.[1] MultiMineral now operates a pilot nahcolite mine shaft near Denver, one of the few existing sources of nahcolite. Since the potentially favorable economics of dry injection are based to some extent on the use of inexpensive sorbents, the use of commercially refined sodium bicarbonate is prohibitively expensive. Recent research has been aimed at studying the use of raw and upgraded trona ore. The mineral trona contains one mole of sodium carbonate, one mole of sodium bicarbonate, and two waters of hydration ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$). Upgraded trona from the Owens Lake, California area, has the potential for providing a good compromise between reactivity, cost, and availability for use as a sorbent in the dry injection process.[2]

Both baghouse and ESP collection devices have been tested with dry injection processes. However, the effect of the reaction between unspent sorbent on collecting bag surfaces and SO_2 remaining in the flue gas seems to overwhelmingly favor the bag collector. Since a significant portion of the SO_2 removal reaction appears to take place on the bag surface, various methods of feeding have been tested:

1) Continuous. After the bag is cleaned, sorbent entrained in the flue gas is continuously supplied to the bag surface from injection points located upstream of the baghouse.

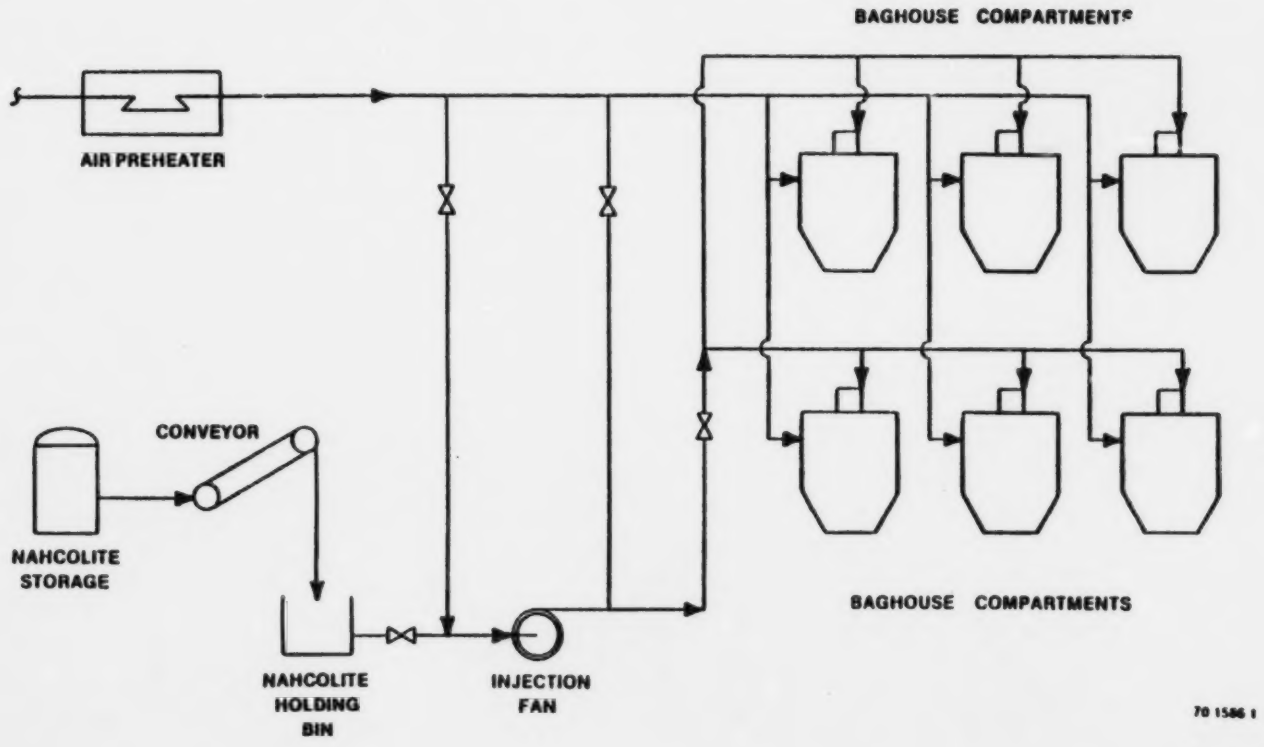

Figure 1-3. Nahcolite dry injection flow diagram.

2) Batch. After the bag is cleaned, all sorbent is added to the bag as a precoat before flue gas flow is resumed.

3) Semi-batch. This feeding method is a combination of methods 1 and 2. After bag cleaning some sorbent is precoated onto the bags and the remainder is added continuously at an upstream injection point.

Sorbent stoichiometry, sorbent particle size, location of injection point, temperature at the point of injection, baghouse air-to-cloth ratio, and bag cleaning frequency are also varied in dry injection programs.

1.2.3 Combustion of Coal/Limestone Fuel Mixtures

The current research on combustion of a coal/limestone fuel mixture has taken two forms:

1) Combustion of a coal/limestone pellet in an industrial spreader-stoker boiler.

2) Combustion of a pulverized coal/limestone mixture in a low-NO_x burner system.

Preliminary results of bench-scale test work on both processes have indicated that up to 80 percent of the available sulfur in the fuel can be retained by the limestone.[3] The ratio of calcium to sulfur in the coal/limestone fuel mixture is important in determining how much sulfur is retained, with higher Ca:S ratios resulting in greater SO_2 removal. The Ca:S ratio is limited, however, by effects on boiler operation and maintenance and fuel combustion properties.

A spreader-stoker boiler has been used in a demonstration program to test the combustion and sulfur retention characteristics of the coal/limestone pellet. The demonstration indicated that sulfur capture levels were achieved that would make the fuel pellet a viable SO_2 control option for low and medium sulfur coals.[4] Data suggest that improved SO_2 retention can be realized if the bed temperature is maintained below 2400°F.

The two-staged combustion concept was employed by Babcock & Wilcox (B&W) to design an advanced low-NO_x burner system. EPA has funded test work to develop the concept of firing a coal/limestone fuel mixture in a B&W low-NO_x burner to reduce SO_2 emissions. Tests conducted by the Energy and Environmental Research Corporation (EERC) with a Utah low sulfur coal have demonstrated 88 percent SO_2 removal with a 3:1 Ca:S mole ratio. This high SO_2 removal has been attributed to the lower flame temperature found in the low-NO_x burner which may help maintain limestone reactivity. EERC has reported that SO_2 removal increased

substantially when the reagent was passed through the pulverizer with the coal. Further testing on a range of combustor sizes is planned during the next few months.

1.3 REFERENCES

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2. Ibid.

3. Giammar, Robert D. et al. "Limestone/Coal Pellet - A viable Method to Control Emissions from Industrial Boilers." (Presented at the 73rd Annual Meeting of the Air Pollution Control Association, Montreal, Quebec. June 22-27, 1980.)

4. Ibid.

SECTION 2

OVERVIEW

Several factors, including mandated increases in coal use and more stringent environmental regulations requiring some type of post-combustion SO_2 control for utility and industrial boilers, have combined to foster increased research and development (R&D) and commercial application of dry flue gas desulfurization (dry FGD) technologies. Interest in the technologies has primarily been spurred by the potential cost savings dry FGD offers over conventional wet FGD, particularly for low sulfur coal applications.

The following sections provide an overview of the R&D and commercial status of three dry FGD technologies: spray drying, dry injection, and combustion of coal/alkali fuel mixtures. Section 2.1 summarizes new developments that have occurred since the last survey was conducted in the Summer and Fall of 1980.* Sections 2.2, 2.3, and 2.4 provide more detail on the commercial and R&D activities in each of the three areas, spray drying, dry injection, and combustion of coal/alkali fuel mixtures, respectively. These sections also include highlights of results from recent demonstration programs. Most of these results were obtained from papers presented at EPA's Sixth FGD Symposium held in Houston, Texas during the last week of October 1980. The fact that one session was dedicated strictly to dry scrubbing is an indication of the increased interest in dry FGD as an effective and potentially lower cost SO_2 control technology.

2.1 SUMMARY OF NEW DEVELOPMENTS

Spray drying continues to be the only commercially applied dry FGD technology. Since Fall 1980, two new industrial and two new utility systems have been sold, bringing the total number of commercial spray drying systems to 17; 11 utility and 6 industrial. (It should be noted here that, for the purposes of this report, the 110-MWe system at Northern States Power Company's Riverside Station has been reclassified from the last survey, where it was labeled as a commercial system, to demonstration system status. Joy/Niro is currently operating the system under a two- to three-year demonstration program, and although Northern States Power has purchased two compartments of the fabric filter portion of the

*The last survey, entitled Second Survey of Dry SO_2 Control Systems, was completed in December 1980. A final report is available through the National Technical Information Service (NTIS). EPA-600/7-81-018. February, 1981.

system, they have not purchased the spray dryer and associated equipment.) At this time, only two commercial systems are operating and they are both applied to industrial boilers: at Celanese Fibers Co. in Cumberland, Maryland, and at Strathmore Paper, Inc. in Woronco, Massachusetts. No utility systems are in commercial operation, although initial start-up procedures have begun at Otter Tail Power Co's Coyote Station in Beulah, North Dakota.

The two new utility spray drying systems will both be applied to low sulfur coal-fired boilers. Basin Electric has awarded Joy/Niro a contract for the utility's 430 MWe Antelope Valley Unit 2. The North Dakota lignite-fired boiler and lime-based spray dryer/fabric filter system will essentially be a duplicate of the Antelope Valley Unit 1 system. The second new utility system has been awarded to the Buell/Anhydro joint venture. The Marquette (Michigan) Board of Light and Power has purchased the system to treat flue gas from a 44 MWe coal-fired boiler located at Marquette's Shiras Municipal Power Plant. This system will also use a lime sorbent and include a fabric filter for collection of fly ash and waste solids. Both new utility system designs will have provisions for recycle of the waste solids. A new industrial system was recently awarded to Joy/Niro by the Department of Energy's Argonne National Labs in Argonne, Illinois. Argonne is converting an existing boiler to fire a nominal 3.5 percent sulfur Illinois bituminous coal. This system will be the first commercial application of spray drying to a boiler firing coal with a sulfur content of greater than 3 percent. (However, the Mikropul system at Strathmore Paper, Inc. is scheduled to undergo compliance/performance testing in February 1981 while the boiler is firing a 3 percent sulfur coal). Sulfur dioxide emissions from the Argonne unit are to be reduced by about 80 percent to meet an SO_2 emission limit of 1.2 lb/million Btu thermal input. Ecolaire Systems, Inc. has sold a lime-based spray dryer/fabric filter system to Container Corporation. The system will treat flue gas from a 170,000 lb steam/hr coal-fired boiler at Container Corporation's facility in Philadelphia, Pennslyvania. More details on each of these systems can be found in Section 2.2 and in the Section 3 discussions for the respective system vendors.

At least two new industrial systems (one for a high sulfur coal-fired boiler) and one utility system are expected to be awarded this winter. Also, there are at least five utilities that have specified only dry FGD or are considering both dry and wet FGD for new units that will go on-line before the end of the decade. (These utilities are listed in Section 2.2).

Developments in spray dryer system design include increased use of off-product recycle and closer approaches to the adiabatic saturation temperature at the dryer outlet. Reslurrying and recycling of dry fly ash/product solids mixture has been shown to significantly increase SO_2 removal for a given stoichiometric ratio of fresh sorbent to inlet SO_2 and to reduce fresh sorbent consumption for a given SO_2 removal efficiency. However, recent test programs have shown conflicting results with respect to the role of fly ash alkalinity in the improved system performance observed with recycle. (See Section 2.2).

Recent test work has also shown that a 20°F approach to saturation at the dryer outlet appears to be the optimum control point in spray dryer system design. This approach has been shown to significantly increase SO_2 removal relative to a 30 or 40°F approach, while still allowing for an adequate margin of safety to protect the downstream control device from moisture condensation and also maintaining dry free-flowing product solids.

These and other, more subtle, refinements of spray drying technology have occurred partly as a result of several recent demonstration programs. A number of the programs are now complete and it appears that future testing may be somewhat limited to high sulfur coal applications. However, there are at least five demonstration programs, of varying size and focus, that will be conducted during 1981. Buell/Anhydro is continuing some EPA-funded test work at the City of Colorado Springs Martin Drake Station and Joy/Niro has begun a two- to three-year large-scale demonstration program at Northern States Power Company's Riverside Station. Also, Combustion Engineering, Inc. has recently started tests on a 100,000 acfm unit at the Gadsden Station of Alabama Power Company, and DOE's Pittsburgh Energy Technology Center (PETC) will soon begin pilot-scale tests to evaluate the performance of a spray dryer/fabric filter system treating flue gas from a high sulfur coal-fired test furnace. Finally, the Electric Power Research Institute (EPRI) has contracted with Stearns-Roger for demonstration tests at Public Service of Colorado's Arapahoe Station.

Dry injection development programs are continuing under DOE and EPRI funding and Buell recently completed EPA-funded tests at the City of Colorado Springs' Martin Drake Station. Recently reported results have shown that a substantial degree of SO_2 removal (up to 90 percent for low sulfur coal applications) is achievable with nahcolite at stoichiometric ratios (moles Na_2O/mole inlet SO_2) of less than 2. But even with this improved performance, relative to earlier tests, the commercial application of dry injection has not occured. Primary restrictions on the commercial development of this technology are sorbent cost and availability, relatively high stoichiometric requirements, and waste disposal concerns related to the undesireable solubility and leachability properties of the sodium-based waste solids.

Development of a process to reduce SO_2 and nitrogen oxides (NO_x) emissions through combustion of pulverized coal/alkali mixtures in a low-NO_x burner is continuing under a 5-year program jointly funded by DOE and EPA. The primary emphasis of this program will be to assess the retrofit potential of the technology for existing boilers.

The EPA is also continuing to fund development of the coal/limestone pellets for control of SO_2 emissions from industrial stoker-fired boilers. However, a continuous 14-day test of the pellet, scheduled for November 1980, was cancelled due to inadequacies in the pellet production process.

Recent test work with both of the technologies, on a pilot-scale, has shown that they are capable of achieving at least 50 percent SO_2 removal. Combustion of coal/alkali fuel mixtures offers a low cost alternative to scrubbing for industrial boilers and interest in these technologies remains strong in light of potential new source regulations for new boilers and the concern over acid rain. Much work remains, however, to fully characterize the impact of these technologies on boiler and particulate control system design and operation.

2.2 SPRAY DRYER SYSTEMS

The following sections summarize current and recently completed commercial and R&D activities in the spray drying area. Also included in the R&D section are highlights from some of the recently completed spray drying demonstration programs. More detail on these programs and the commercial activities can be found in Section 3.

2.2.1 Commercial Activities

Table 2-1 lists the eleven utility (a total of over 3200 MWe) and six industrial systems that had been sold as of January 1981. This table shows the system purchaser and vendor along with key features of system design and operation.

Only two systems were fully operational at this writing: the Rockwell/Wheelabrator-Frye system at Celanese Fibers Company's Amcelle plant in Cumberland, Maryland and the Mikropul system at Strathmore Paper, Inc. in Woronco, Massachusetts. The first utility system to become operational will likely be another Rockwell/Wheelabrator-Frye system, this one at the Coyote Station of Otter Tail Power Company. Initial start-up procedures at Coyote began in January 1981. Construction on several other utility systems, including Antelope Valley Unit 1 (Basin Electric Power Cooperative), Laramie River (also Basin Electric), and Colorado Ute Power Company's Craig Station is reportedly on schedule with the dates shown in Table 2-1.

TABLE 2-1. KEY FEATURES OF COMMERCIAL SPRAY DRYING SYSTEMS SOLD TO DATE

System Purchaser/Vendor Utility	Location/Size	System Description	Coal	SO_2 Removal Guarantee	Reported Capital Cost	Reported Operating Cost	Status
Otter Tail Power Co./ Combustion Engineering-Pyro.	Coyote Station, Beulah, ND/ Unit 1, 410 MW(1,890,000 acfm).	Four parallel spray dryers, with 3 centrifugal atomizers each, followed by fabric filter with dacron bags. Will initially use commercial soda ash. Sorbent utilization guarantee of 80%.	North Dakota lignite; 0.76% S average; 7050 Btu/lb; 7% Ash.	70% for all fuels.	$32,000,000 ($78/kW)[a].	$6,580,000 ($2.5 mills/kWh)[a]. Does not include waste disposal.	Start-up scheduled for mid-1981.
Basin Electric Power Coop/ Joy-Niro.	Antelope Valley, Beulah, ND/ Unit 1, 410 MW (2,200,000 acfm).	Five parallel spray dryers (one spare), single rotary atomizer per dryer, followed by fabric filter with teflon-coated fiberglass bags. Lime sorbent with partial recycle of solids. Ball mill slaker.	North Dakota lignite; 0.68% S average; 1.22% S maximum.	62% for average S coal; 78% for maximum S coal.	$49,665,100 ($113/kW)[b].	$2,270,834/yr (90.8 mills/kWh)[b]. Lime cost = $1,102,500 ($60/ton). Does not include waste disposal.	Start-up scheduled for April 1982.
Basin Electric Power Coop/ Babcock & Wilcox.	Laramie River, Wheatland, Wyoming/Unit 3, 500 MW (2,810,000 acfm).	Four parallel reactors (one spare) with 12 fluid nozzles each. Each reactor followed by an ESP. Lime sorbent, no solids recycle.	Wyoming subbituminous, 0.54% S average; 0.81% S maximum; 8160 Btu/lb; 8% Ash.	82% for average S coal; 90% for maximum S coal.	$49,807,000 ($83/kW)[b].	$2,571,000/yr (90.7 mills/kWh)[b]. Lime cost = $1,396,570 ($60/ton). Does not include waste disposal costs.	Start-up scheduled for Spring 1982.
Basin Electric Power Coop/ Joy-Niro	Antelope Valley, Beulah, ND/Unit 2,420 MW (2,390,000 acfm).	Design identical to Antelope Valley Unit 1 (see above).	North Dakota lignite; 0.68% S average; 1.22% S maximum.	62% for average S coal; 78% for maximum S coal.	$54,000,000[b] ($126/kW)	Same as Antelope Valley Unit 1 (See above)	Start-up scheduled for 1985.
Marquette Board of Light and Power/Swell-Anhydro.	Shiras Municipal Power Plant, Marquette, Michigan/ 44 MW (220,000 acfm).	Single spray dryer with rotary atomizer. Reverse-air fabric filter. Lime sorbent. Solids recycle.	1.5% S western subbituminous 15% ash. 7700 Btu/lb.	90% design efficiency.	Not available.	Not available.	Start-up scheduled for Fall 1982.
Farmers Electric/ Joy-Niro. (2)	Springerville Station/ Units 1 and 2; 350 MW each.	Spray dryer/fabric filter design. Lime sorbent. Rotary atomization.	New Mexico coal; 0.69% S.	61%.	Not available.	Not available.	Unit 1 scheduled to start-up in late 1984; Unit 2 in 1985.
United Power Association/ Research-Cottrell.	Stanton Station, Stanton, North Dakota/65 MW.	Spray dryer/fabric filter rotary atomizers, possibly multiple atomizers per dryer. Lime sorbent.	Low and intermediate sulfur subbituminous Montana coal.	Not available.	$5,000,000 ($77/kW)	Not available.	Start-up scheduled for 1981.

TABLE 2-1. (Continued). KEY FEATURES OF COMMERCIAL SPRAY DRYING SYSTEMS SOLD TO DATE

System Purchaser/Vendor / Utility	Location/Size	System Description	Coal	SO_2 Removal Guarantee	Reported Capital Cost	Reported Operating Cost	Status
Platte River Power Authority/ Joy-Niro.	Rawhide Station/Unit 1 250 MW.	Spray dryer/fabric filter design. Rotary atomizers. Lime sorbent.	Western subbituminous coal; 1.3% S.	80%.	Not available.	Not available.	Start-up scheduled for 1983.
Colorado-Ute Association/ Babcock & Wilcox.	Craig Station/Unit 3 450 MW.	Horizontal spray dryers with nozzle atomizers, followed by fabric filter. Solids recycle. Ball mill slaker for lime sorbent.	0.7% S, 8950 Btu/lb, 16% Ash design coal; 0.46% S, 10250 Btu/lb,	87% for design coal.	($100/kW)	Not available.	Initial operation in November 1982. Commercial operation in April 1983.
Sunflower Electric Coop/ Joy-Niro.	Holcombe Station/Unit 1 349 MW.	Spray dryer/fabric filter. Rotary atomization. Lime sorbent.	Western subbituminous coal.	80%.	Not available.	Not available.	Start-up scheduled for 1983.
Industrial							
Celanese Fibers Co./ Bartwell/Chemiebeton-Heyo.	Amelia plant, Cumberland, Maryland/65,000 acfm (110,000 lb steam/hr).	Spray dryer with single rotary atomizer followed by fabric filter with felt/ fiberglass bags. Paste slaker for lime sorbent. No solids recycle.	1.5% S and 2 to 2.5% S eastern coals.	70% for 1.5% S coal, 87% for 2.0% S coal.	$1,250,000[d].	Not available.	Operational. Passed Maryland state compliance tests in February 1980. Has achieved guaranteed removal.
Strathmore Paper Co./ Chicopee, Inc.	Worcester, Massachusetts/ 40,000 acfm (85,000 lb steam/hr).	Spray dryer with four two-fluid nozzles, followed by fabric filter with specially finished acrylic bags.	2.3 to 3% S eastern coal.	75%.	$1,400,000[d,e].	$900/day[f].	Operational. Now achieving removal guarantee.
University of Minnesota/ Envirotech Development Co. (Environmental Products Division).	Univ of Minnesota/2 Units at 120,000 acfm each.	Two spray dryers-one with single, other with multiple rotary atomizers-followed by fabric filter with fiberglass bags. Lime sorbent.	Subbituminous coal; 0.6 to 0.7% S.	70%.	$3,300,000[d,f].	Not available.	Commercial operation in Fall 1981.
Calgon/Bir--Joy	57,000 acfm.	Spray dryer/fabric filter. Rotary atomizer. Soda ash sorbent. Removing SO_2 and HCl from 1700°F gases. Solids recycle.	1 to 3% S coal, 1000-8000 ppm SO_2, 8000 ppm halides.	75% SO_2; to 7 HCl	$1,600,000[d,g].	Not available.	Under construction.
Argonne National Labs/ Niro-Joy.	Argonne, Illinois/ 170,000 lb steam/hr.	Single spray dryer with rotary atomizer followed by pulse-jet fabric filter. Lime sorbent, solids recycle.	3.5% S Illinois bituminous coal	78.6% SO_2 removal (1.2 lb/10^6 Btu)	Not available.	Not available.	Start up scheduled for Winter of 1981-82.
Container Corporation/ Envirotech Systems	Philadelphia, PA/ 170,000 lb steam/hr.	Spray dryer with single rotary atomizer followed by pulse-jet fabric filter. Lime sorbent, solids recycle.	1% S Coal	Not available.	Not available.	Not available.	Construction scheduled for April 1981, start-up in October 1981.

FOOTNOTES TO TABLE 2-1:

[a]Capital Cost for complete turnkey installation from air preheater outlet to stock connection, exculding I.D. fans (1977$). Source: Johnson, O.B. et. al. "Coyote Station, First Commercial Dry FGD System." (Presented at 41st Annual American Power Conference, Chicago, Illinois. April 23-25, 1979.)

[b]Evaluation based on 35-year plant life, 75% capacity factor (1981$). Source: Janssen, K.E. and R.L. Eriksen. "Basin Electric's Involvement with Dry Flue Gas Desulfurization." In Proceedings: Symposuim on Flue Gas Desulfurization - Las Vegas, Nevada, March 1979; Volume 2. EPA-600/7-79-167. July 1979. pp 629-653.

[c]Kelly, M.E. and S.A. Shareef. Meeting notes at Babcock & Wilcox. Barberton, Ohio. June 1980.

[d]Stern, J.L. "Dry Scrubbing for Industrial Flue Gas Desulfurization: State-of-the Art, 1980." (Presented at the 89th National Meeting of AICHE. Portland, Oregon. August 17-20, 1980.)

[e]From "ground-up". (1979$)

[f]"Straight-through system". (1980$)

[g](1980$)

[h](1980$)

All of the utility systems are designed for relatively low sulfur western coals (generally less than 1.5 percent sulfur). Sulfur dioxide removal guarantees range from 61 to 87 percent. Other than the Coyote Station and Laramie River systems, all the designs include a fabric filter for particulate collection and are based on the use of a lime based sorbent. Commercial soda ash will be the sorbent for initial operation at Coyote, and B&W will use an ESP for particulate control at Laramie River. Depending on site specific factors, some designs include hot or warm gas bypass and/or solids recycle. Rotary atomizers, whether in a single or multiple atomizer per dryer configuration, appear to be the choice for most utility systems. However, B&W does use "Y-jet" steam/air atomized nozzles based on standard oil burner technology for their horizontal reactor. Other basic differences in the utility system designs include variations in spray dryer gas flow design and reagent preparation techniques (paste slaker versus ball mall slaker).

One of the most recent industrial systems awarded will treat flue gas from a boiler firing a 3.5 percent sulfur Illinois bituminous coal. The system contract has been awarded to the Joy/Niro joint venture by DOE's Argonne National Labs. It will be the first system applied to a boiler firing coal with more than 3 percent sulfur. Joy/Niro has offered an 80 percent SO_2 removal guarantee to meet an SO_2 emission limit of 1.2 lb/million Btu thermal input. The system design will include solids recycle.

In addition to the commercial systems already sold, at least five utilities are considering dry FGD only or dry and wet FGD for units that will go on line before the end of the decade.[1] These utilities, all of which are slated to fire low sulfur coal and are subject to the recently promulgated NSPS for utility boilers, are shown in Table 2-2. The system for Sierra Pacific Power Company's Valmy (Nevada) Station is expected to be awarded this winter. Also expected this winter is the award of a contract for another industrial system to serve a high sulfur coal-fired boiler.

Part of the reason for the increasing commercial application of dry FGD is the potential cost savings the technology offers when compared with conventional wet lime/limestone scrubbing. Results of a recent EPA-funded TVA conceptual cost study support this premise.[2] The study compared the capital and annual costs of a lime spray dryer/fabric filter system with that of a wet limestone scrubbing system for a new 500 MWe power plant. Costs were developed for three fuels, low sulfur western coal, low sulfur eastern coal, and high sulfur eastern coal. The spray dryer designs were based on vendor information, while the limestone scrubbing design (which includes an ESP upstream of the scrubber) was based on information from the EPA Shawnee test facility and general

Table 2-2. UTILITIES CONSIDERING DRY FGD FOR NEW UNITS[a]

Utility	Plant Site	Coal	Comments
Central and Southwestern Services Company	Coleto Creek Unit 2	0.4% average sulfur; subbituminous	Considering only dry FGD. Scheduled for 9/86 start-up.
Cajun Electric	Big Cajun Unit 3	Lignite	Considering dry scrubbing for 540 MW unit.
East Kentucky Power Coop.	J.K. Smith, Units 1 and 2	-	Considering dry and wet FGD for each 650 MW unit. Units scheduled for 1/85 and 1/86 start-up.
Nebraska Public Power	Fossil III	0.36% sulfur	Considering dry scrubbing for 650 MW unit to go on-line in 1987.
Sierra Pacific Power	Valmy, Nevada	Low sulfur coal	Considering dry FGD or low sulfur coal for 276 MW unit. Start-up scheduled for August 1984.

[a]Source: Smith, M., et al. EPA Utility FGD Survey: July-September 1980. Prepared for the U.S. Environmental Protection Agency. PedCo Environmental, Inc., Cincinnati, Ohio. EPA-600/7-80-029d. October 1980.

industry information. Table 2-3 shows the results of the cost comparison. Lime spray drying is reported to be less expensive on a capital and annual cost basis for all three coals. The higher absorbent cost associated with the spray dryer process, particularly for the high sulfur coal case, is offset by the lower spray dryer equipment costs. It should be noted that the spray drying operating costs are based on limited data and may change as more experience is gained with commercial utility systems.

Another EPA-funded conceptual economic study was performed to estimate the cost of retrofitting a spray drying system to a northeastern utility power station.[3] The costs were assumed to be associated with conversion to low sulfur coal-firing from oil-firing. The cost estimates were based on vendor budgetary quotes. The total installed costs for the spray dryer/fabric filter system ranged from $89/kW to $118/kW for a generalized northeastern location.

As shown in Table 2-4, there are about thirteen firms that currently offer a commercial spray drying system. Most of these firms have conducted or are conducting demonstration programs to establish a basis for design of their commercial systems. Results of some of the recently completed programs are summarized in the following section.

2.2.2 Research and Development Activities

Table 2-5 shows the status of seven major spray drying demonstration programs. Results from three of these programs, Buell/Anhydro at Martin Drake, Research-Cottrell at Comanche, and Babcock & Wilcox at Jim Bridger, were presented at the recent EPA-sponsored FGD Symposium. Also,[4] Flakt has recently published some results of their Jim Bridger tests.

In general, the purpose of the demonstration tests are to identify the process design and operating parameters that most significantly influence SO_2 removal, to characterize the effects of these parameters over a range of process conditions, and, in some cases, to determine the optimum value for the parameter which will provide for maximum SO_2 removal and minimize sorbent use.

In addition to the inlet SO_2 concentration, three process parameters which have strong influence on system performance are sorbent stoichiometric ratio, approach to saturation at the dryer outlet, and recycle of waste solids/fly ash mixture. Results of test work with regard to these parameters are highlighted below. There are several other parameters including the size of the atomized slurry droplet, reagent preparation techniques, gas residence time in the dryer, and inlet flue gas temperature that can significantly affect SO_2 removal and the test programs evaluated these parameters as well. The reader should, however, refer to Section 3 of this report or to the individual papers for details on these results.

Table 2-3. Comparison of Capital Costs and Annual Revenue Requirements
FOR WET AND DRY FGD SYSTEMS FOR A NEW 500 MW POWER PLANT[a]

	Capital Cost ($/kW)	Levelized Annual Revenue Requirements (mills/kWhr)
Low Sulfur Western Coal		
Lime spray drying[b]	144 to 152	8.7 to 9.1
Limestone wet scrubbing[c]	168 to 176	10.5 to 10.9
Low Sulfur Eastern Coal		
Lime spray drying[b]	144 to 152	8.4 to 8.7
Limestone wet scrubbing[c]	180 to 188	11.3 to 11.6
High Sulfur Eastern Coal		
Lime spray drying[b]	180 to 188	14.5 to 14.9
Limestone wet scrubbing[c]	236 to 244	16.4 to 16.7

[a] Source: Burnett, T.A., et al. Spray Dryer FGD: Technical Review and Economic Assessment. (Presented at EPA's Sixth FGD Symposium. Houston, Texas. October 28-31.) Tennesse Valley Authority. Muscle Shoals, Alabama.

[b] Includes fabric filter.

[c] Includes ESP upstream of scrubber.

Table 2-4. FIRMS OFFERING A COMMERCIAL SPRAY DRYING FGD SYSTEM

Firm	Design features[a]	Number of Systems Sold in the United States
Babcock and Wilcox	Horizontal dryers with "Y-jet" steam/air atomized nozzles. Favor ESP but also offer fabric filter.	2 utility (does not plan to bid industrial)
Buell/Anhydro	Spray dryer followed by fabric filter. Single centrifugal atomizer per dryer.	1 utility
Combustion-Engineering	Spray dryer followed by fabric filter. Multiple ultrasonic nozzles per dryer.	None
Ecolaire	Spray dryer followed by fabric filter. Tested primarily with single rotary atomizers.	1 industrial
Flakt	Horizontal and vertical spray dryer with either fabric filter or ESP. Nozzle atomization.	No systems in U.S.
Joy/Niro	Spray dryer followed by fabric filter. Single rotary atomizer per dryer.	6 utility,[b] 2 industrial
Kennecott	Spray dryer/fabric filter with single rotary atomizers	1 industrial (2 units)
Koch	Spray dryer. Nozzle atomizers.	None
Mikropul	Spray dryer/fabric filter. Multiple nozzle atomizers per dryer. Also offer centrifugal atomizers.	1 industrial
Research-Cottrell	Spray dryer/fabric filter. Multiple rotary atomizers per dryer. Nozzle atomizers for sodium-based systems.	1 utility
Rockwell	Spray dryer/fabric filter. Rotary atomizers - multiple per dryer for utility, single for industrial.	1 utility[c] 1 industrial[c]

Table 2-4. (Continued). FIRMS OFFERING A COMMERCIAL SPRAY DRYING FGD SYSTEM

Firm	Design features[a]	Number of Systems Sold in the United States
Stork-Bowen Engineering	Spray dryer followed by a cyclone and a Leisegang scrubber or followed by a baghouse.	No systems in U.S.
Wheelabrator-Frye	Spray dryer/fabric filter or ESP. Air atomized nozzles, also offer rotary atomization.	1 utility,[c] 1 industrial.[c]

[a]The reported design features are based on commercial systems sold to date and information presented in Section 3. Many vendors may offer additional designs depending on the system purchaser's specification.

[b]Does not include Riverside unit at Northern States Power which will be operated as demonstration system for the near future.

[c]Sold by Rockwell/Wheelabrator-Frye joint venture which was dissolved in January 1980.

TABLE 2-5. MAJOR SPRAY DRYING DEMONSTRATION ACTIVITIES[a,b]

Vendor/Agency	Location	Size	Comments
Babcock & Wilcox[c]	Pacific Power & Light's Jim Bridger Station	120,000 acfm	Testing completed.
Buell/Anhydro[c]	Colorado Springs-Martin Drake Station	20,000 acfm	EPA-funded testing still in progress. Bulk of program has been completed.
Flakt, Inc.	Pacific Power & Light's Jim Bridger Station	15,000 acfm	Testing complete.
Combustion Engineering	Alabama Power's Gadsden Station	100,000 acfm	Testing has begun and is expected to run for remainder of 1981.
Ecolaire Systems, Inc.	Nebraska Power's Gerald Gentleman Station	10,000 acfm mobile pilot plant	Testing near completion.
Research-Cottrell[c] (Cottrell Environmental Sciences)	Public Service of Colorado's Comanche Station	10,000 acfm	Testing completed in January 1981.
Electric Power Research Industry (EPRI) (Stearns-Roger will conduct the tests).	Public Service of Colorado's Arapahoe Station	2½ MWe equivalent of flue gas.	System in design and construction phase. (Spray dryer and associated equipment will be supplied by Stork-Bowen).
Joy-Niro	Northern States Power's Riverside Station	680,000 acfm	In start-up.

[a]More information on each of these programs can be found in Section 3.

[b]There are also several other smaller demonstration tests being conducted by private firms, and the Department of Energy's Pittsburgh Energy Technology Center will begin tests soon on a 2500 acfm unit.

[c]Results presented in FGD Symposium - related papers.

Stoichiometric Ratio

Figures 2-1, 2-2, and 2-3 show the effect of increasing stoichiometric ratio on SO_2 removal. (Figure 2-2 shows only removal across the spray dryer). All of the test data shown were collected at inlet SO_2 concentrations of 2500 ppm or less. It should be noted that stochiometric ratios shown are reported on the basis of moles of CaO or $Ca(OH)_2$ per mole of inlet SO_2. Removal efficiencies range between 70 and 85 percent at a stoichiometric ratio of 1.4 moles sorbent/mole inlet SO_2 depending on the gas-side temperature drop over the dryer and whether or not solids recycle is used. Both increased temperature drop over the dryer and use of solids recycle contribute to increased SO_2 removal. At a stoichiometric ratio of 1, SO_2 removal generally falls off to between 60 and 75 percent. From Figure 2-1 it appears that stochiometric ratios of 1.6 to 1.8 or greater would be required for 90 percent SO_2 removal (with solids recycle) at an inlet SO_2 concentration of 1500 ppm.

Also, Figure 2-1 shows that, for a given stochiometric ratio, SO_2 removal is lower for higher inlet SO_2 concentrations. For example, at a stoichiometric ratio of 1.1 and an inlet SO_2 concentration of 2000 ppm or greater, SO_2 removal efficiency is between 60 and 65 percent (without solids recycle) while at inlet SO_2 concentrations of 1500 ppm or less the SO_2 removal ranges from 70 to 75 percent. Increased stoichiometric requirements at higher inlet SO_2 reduces with recycle since sorbent utilization can be relatively poor on a once-through basis. The relationship between SO_2 removal efficiency and stoichiometric ratio has been expressed by the simple mathematical model:[5]

$$\ln(1-E) = -KS_pS_R\theta$$

$$= -K'S_R$$

or

$$E = 1 - e^{-K'S_R}$$

where E = SO_2 removal efficiency, fractional

K = Proportionality Constant

S_p = Specific surface of lime, ft^2/lb of lime

S_R = moles lime/mole SO_2

θ = Gas residence time, sec

$K' = KS_p\theta$

Figure 2-4 shows this relationship graphically for inlet SO_2 concentrations less than 1500 ppm.

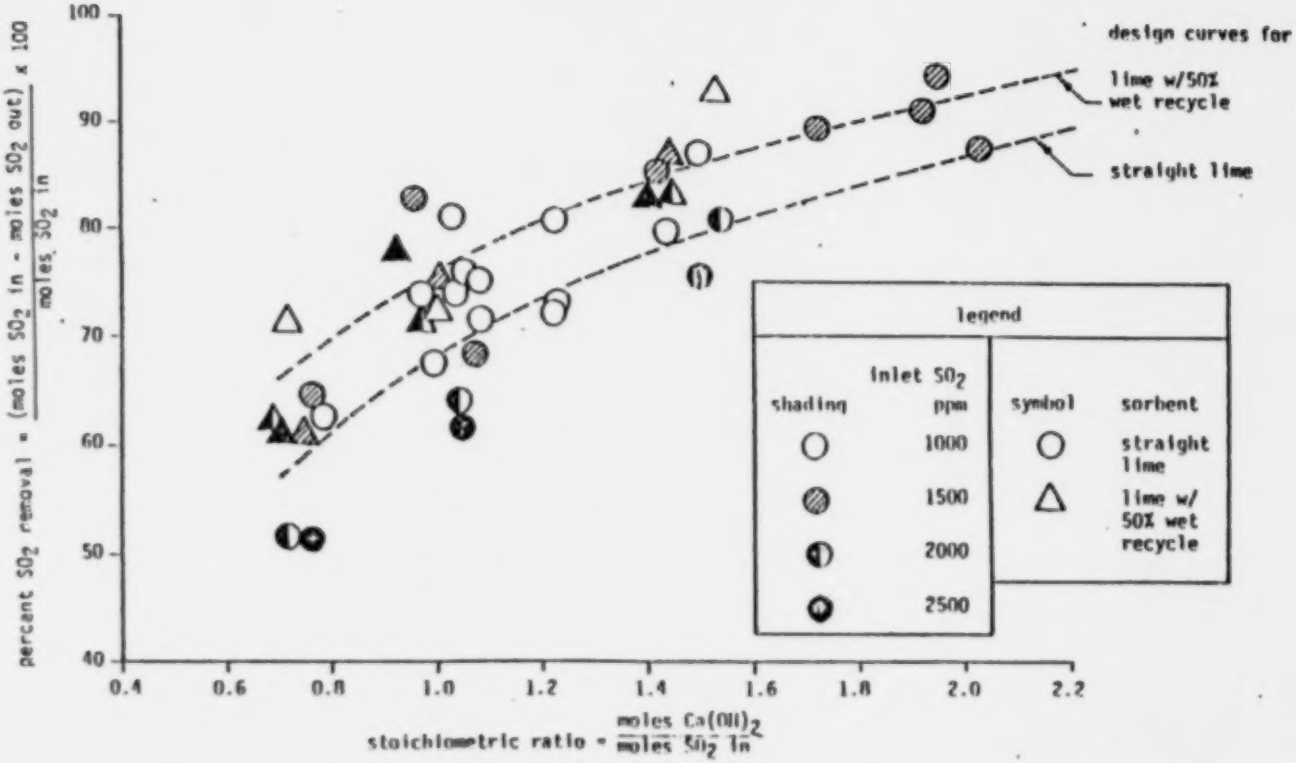

Figure 2-1. Percent SO_2 removal vs stoichiometric ratio - Buell/Anhydro (For 10° to 13°C (18° to 24°F) approach to saturation at the outlet, t_p, inlet gas temperature = 150° to 180°C (290° to 360°F), residence time = 10 sec).

Source: Parsons, et al. (Reference 7)

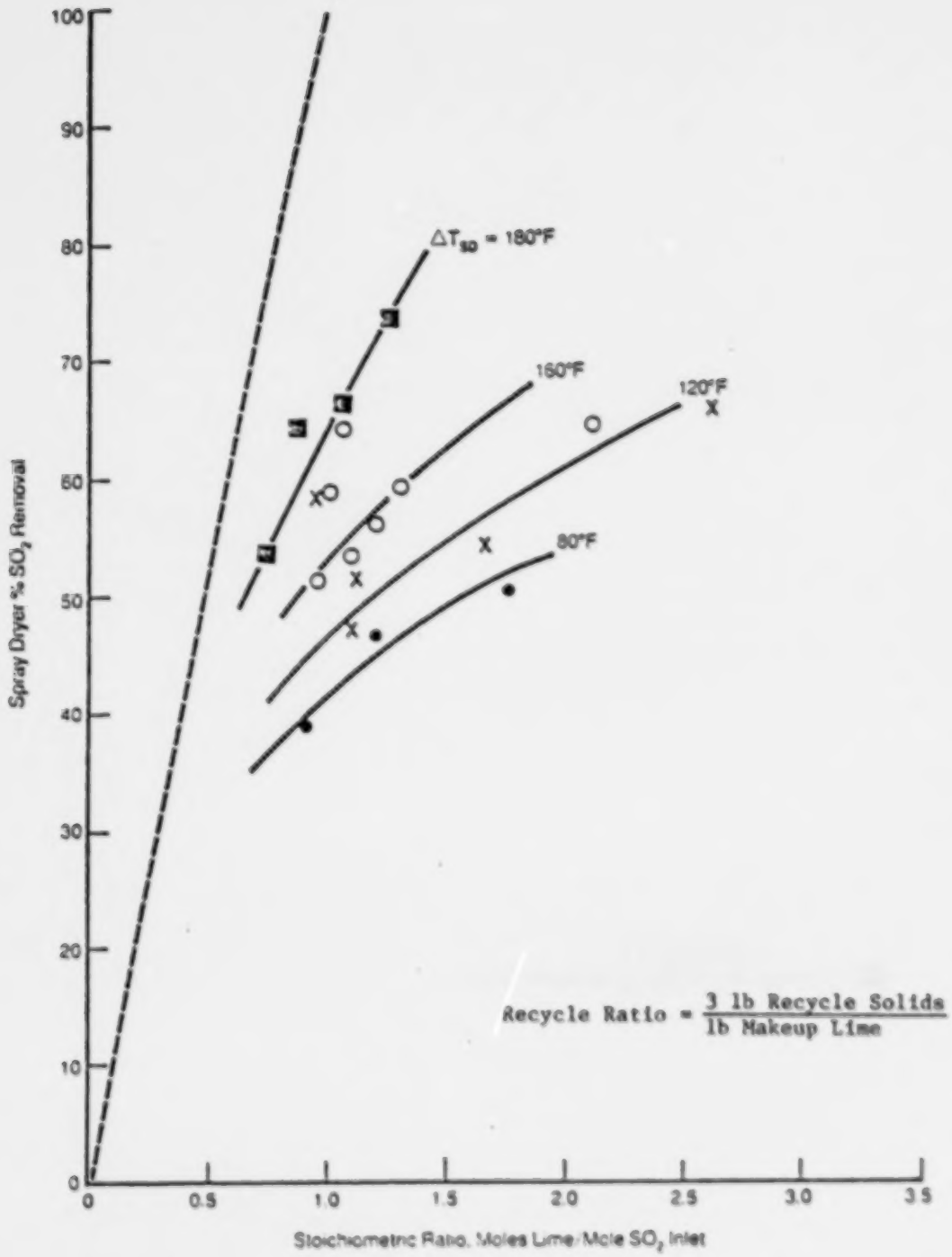

Figure 2-2. Percent SO_2 removal vs stoichiometric ratio - Research-Cottrell (Spray dryer only).

Source: Stevens, N. (Reference 8)

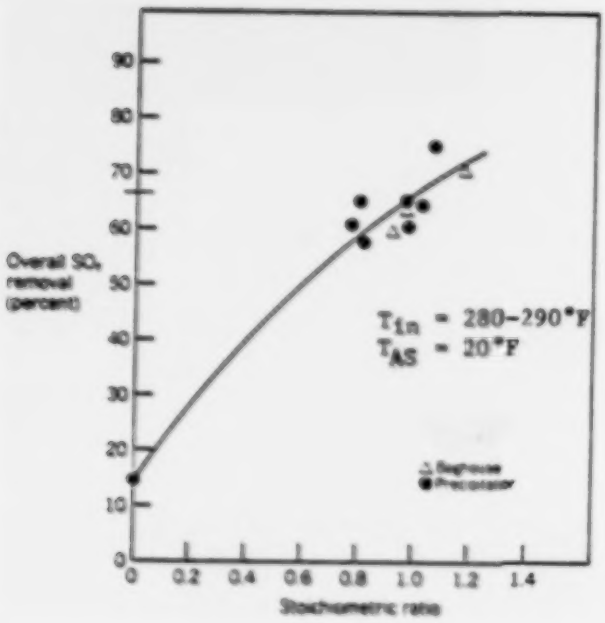

Figure 2-3. Percent SO_2 removal vs. stoichiometric ratio.
Source: Hurst, et al. (Reference 6).

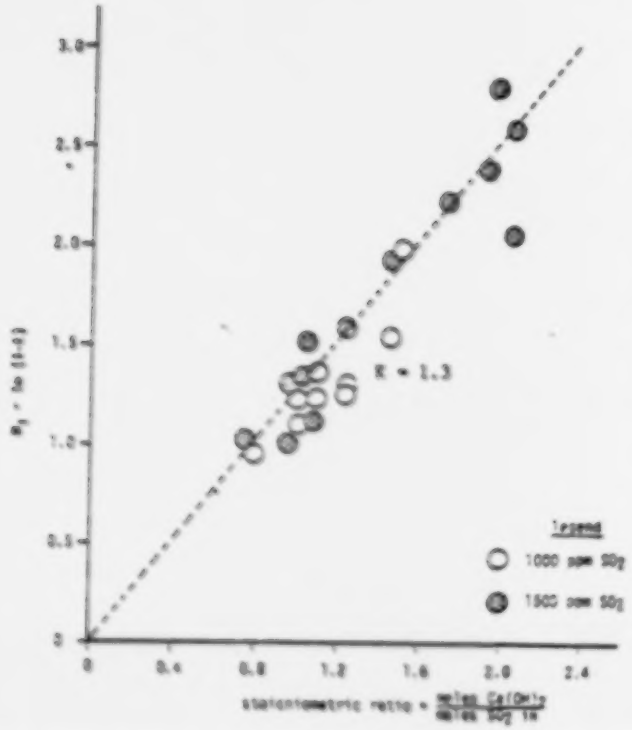

Figure 2-4. Correlation of removal efficiency with stoichiometric ratio - Buell/Anhydro. (18° to 24°F approach to saturation; no solids recycle)
Source: Parsons, et al. (Reference 7).

Approach to Saturation

Figures 2-5 and 2-6 show the effect of operating at a closer approach to the adiabatic saturation temperature of the gas at the dryer outlet. B&W has reported that SO_2 removal efficiency can be increased by approximately 10 percent by reducing the approach to saturation from 30°F to 20°F.[6] The improvement in SO_2 removal has been found to be mainly a result of the increased moisture that is retained by the solids as the flue gas becomes cooler and more humid near the saturation temperature. There is a practical limit, however, to the amount of moisture that can be retained by the solids without causing difficulties in discharging the solids from the dryer. Also, moisture condensation in the downstream particulate control device must be avoided. Most vendors have recommended 20°F as the minimum approach to saturation for commercial system design.

Solids Recycle

Figures 2-7 and 2-8 show the results of tests designed to evaluate the effects of recycling the spent solids/fly ash mixture. Recycle of the waste solids appears to improve spray dryer performance in two ways. First, recycle provides a mechanism for utilization of unreacted reagent and available fly ash alkalinity. Secondly, the recycled fly ash appears to act as a surface catalyst, providing an alternate site for calcium sulfite to precipitate, thus decreasing the amount of product solids formed on the lime particles and reducing the resistance to SO_2 mass transfer.[7] The latter fact suggests that recycling solids may improve system performance even when the ash is relatively low in available alkalinity, as are many fly ashes from eastern high sulfur coals.

Most system designs reslurry the product solids in a loop separate from the fresh sorbent preparation loop and then combine the two slurries just upstream of the atomizer. This method is used to allow closer control of the recycle slurry pH, which has been found to substantially affect the benefits realized by solids recycle.[7]

Figure 2-8 indicates that the source of the solids recycled (spray dryer or fabric filter) does not significantly affect SO_2 removal. Figure 2-8 also shows that recycle is particularly beneficial at high stoichiometric ratios by allowing for the use of large amounts of unreacted sorbent.

The demonstration programs also involve evaluation of sorbents other than lime. In an effort to evaluate the viability of less expensive limestone for the spray drying process, Buell/Anhydro ran tests using a pulverized limestone slurry with adipic acid addition. Adipic acid appears to benefit the reaction between $CaCO_3$ and SO_2, but the maximum SO_2 removal achieved on a straight-through basis was less than 40 percent at an inlet SO_2 concentration of 1000 ppm.[8] Buell/Anhydro also ran tests with trona, which exhibited better SO_2 removal and sorbent utilization than lime. However, the soluble nature of the waste products and the cost and/or availability of trona may restrict the use of this sorbent in commercial systems.

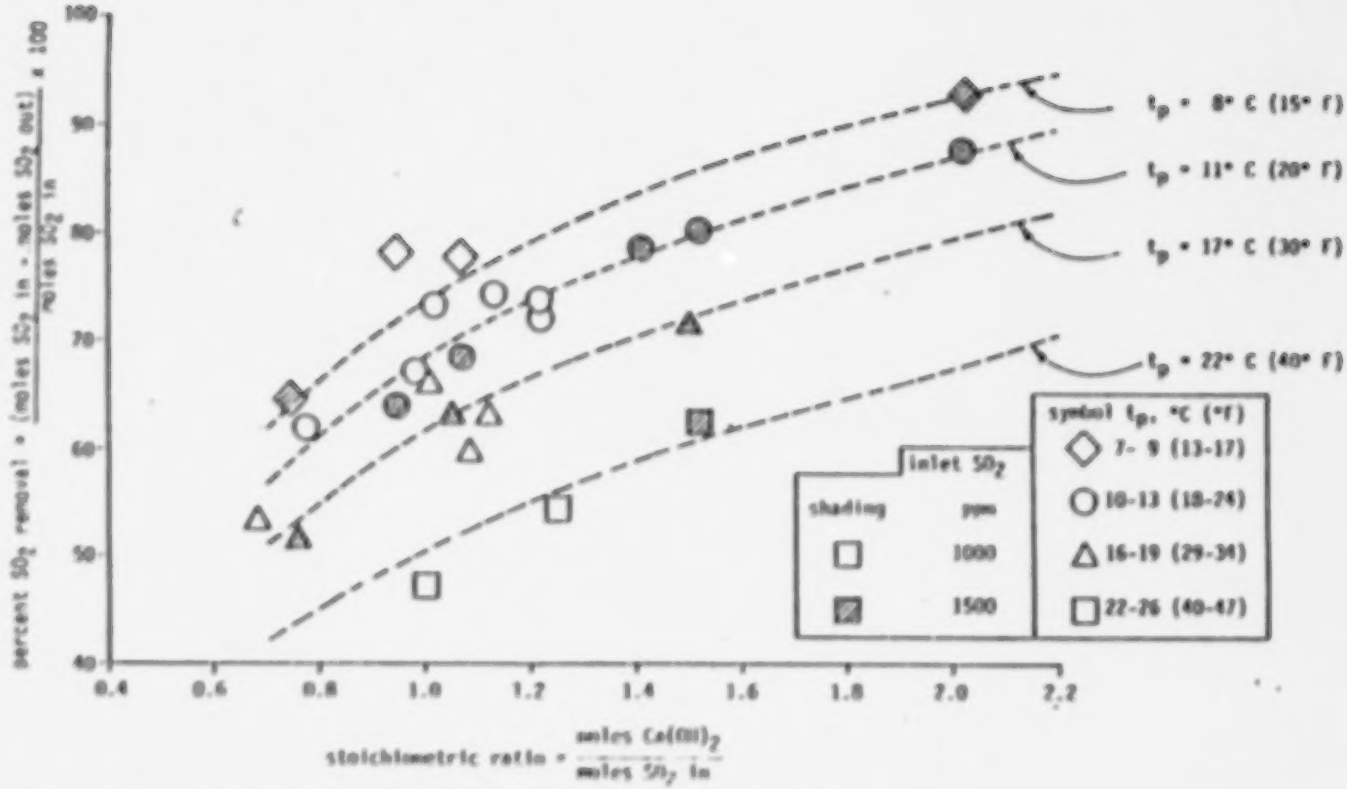
t_p = 8° C (15° F)
t_p = 11° C (20° F)
t_p = 17° C (30° F)
t_p = 22° C (40° F)
symbol t_p, °C (°F)
7- 9 (13-17)
10-13 (18-24)
16-19 (29-34)
22-26 (40-47)
inlet SO_2
shading
ppm
1000
1500
percent SO_2 removal = (moles SO_2 in - moles SO_2 out) / moles SO_2 in × 100
stoichiometric ratio = moles $Ca(OH)_2$ / moles SO_2 in

Figure 2-5. Effect of approach to saturation, t_p, at dryer outlet on SO_2 removal - Buell/Anhydro (no solids recycle).

Source: Parsons, et al. (Reference 7)

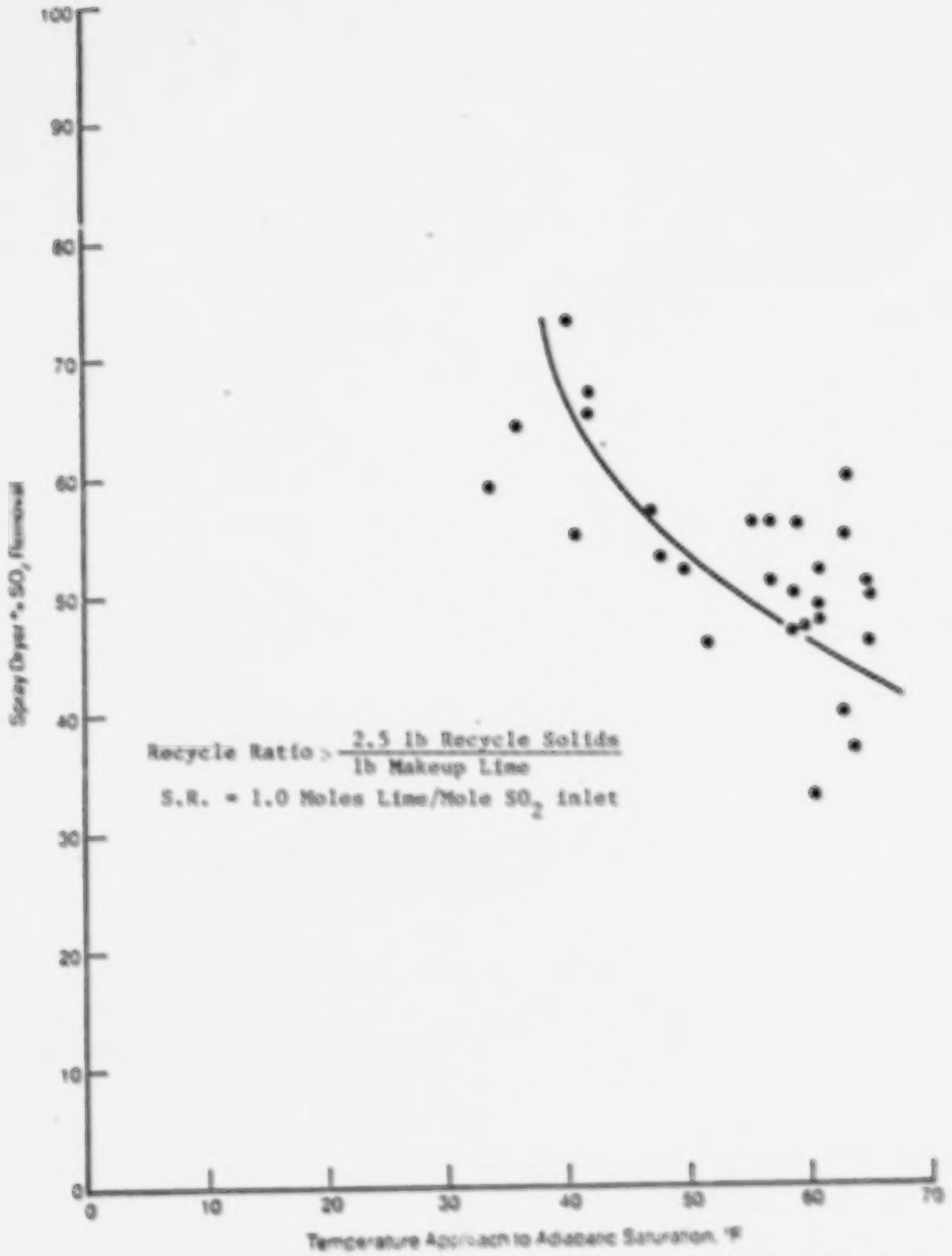

Figure 2-6. Effect of approach to saturation on SO_2 removal - Research-Cottrell (Spray dryer only).

Source: Stevens, N.J. (Reference 8)

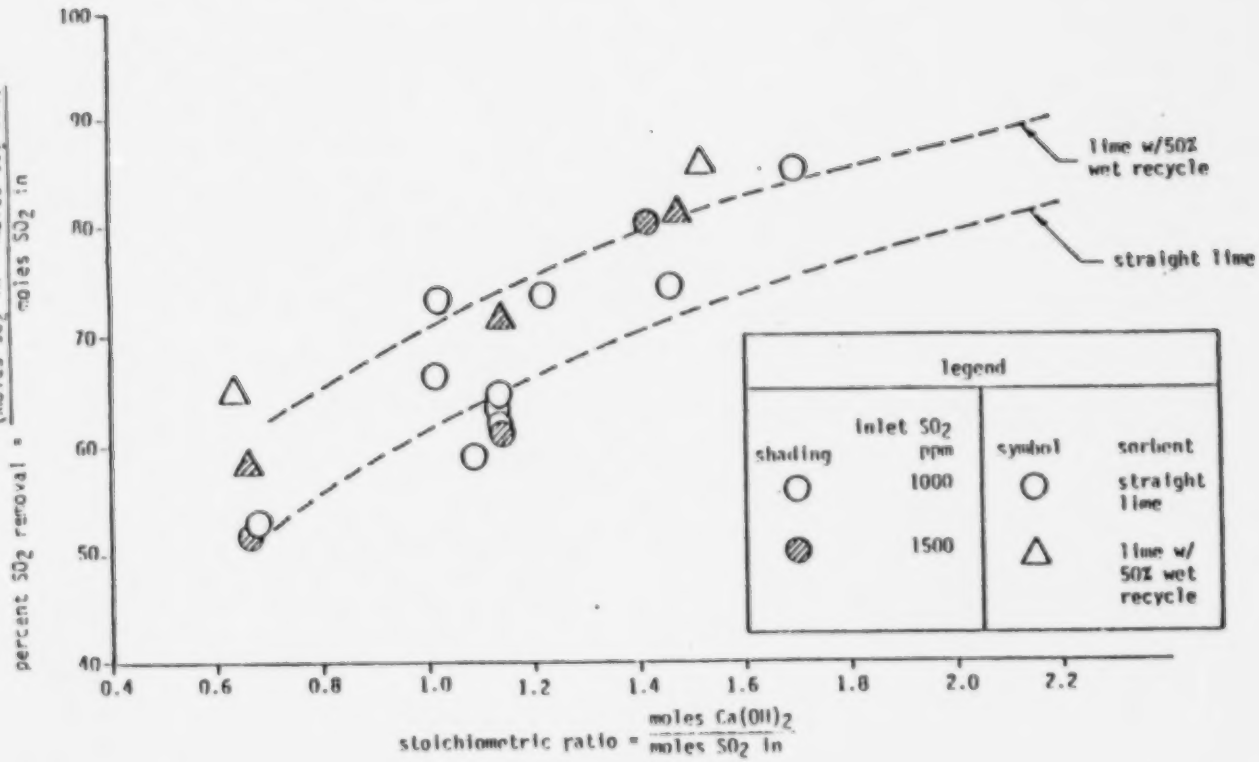

Figure 2-7. Effect of solids recycle on SO_2 removal - Buell/Anhydro (29° to 34°F approach to saturation, 290° to 360°F inlet, gas temperature).

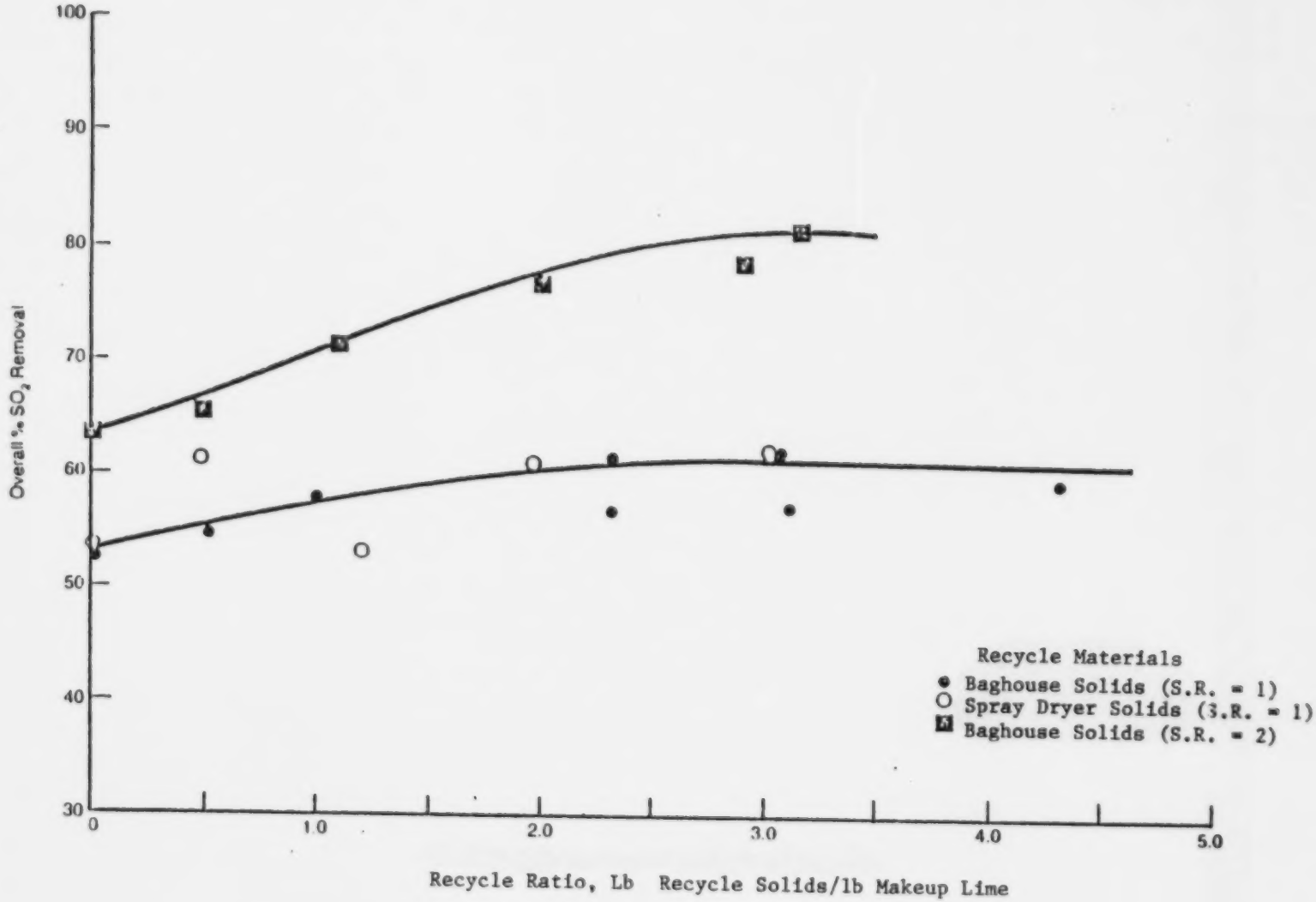

Figure 2-8. Effect of recycle ratio on SO_2 removal - Research-Cottrell

The current focus of the on-going and planned demonstration programs appears to be toward higher inlet SO_2 concentrations and obtaining a better definition of spray dryer performance limits. And, of course, many of the programs will evaluate more subtle refinements to the technology such as lime quality, slaking technique, and recycle methods. Another area of emphasis will likely be development of more sophisticated process control techniques to improve system reliability and reduce sorbent-related operating costs.

2.3 DRY INJECTION SYSTEMS

Presently, there are no plans for the construction of any commercial dry injection systems. However, there are several demonstration programs being conducted. Demonstration-scale dry injection systems have been or are being operated through funding by the Department of Energy (DOE), the Environmental Protection Agency (EPA), and the Electrical Power Research Institute (EPRI). The current status of several demonstration programs is presented in Table 2-6.

Investigations with a number of sorbents have shown that only sodium sorbents, such as sodium bicarbonate, nahcolite and trona ores, provide satisfactory SO_2 removal. However, nahcolite appears to be the most reactive sorbent. Removal efficiencies of up to 90 percent have been reported with a nahcolite sorbent. There are many important variables that influence SO_2 removal during dry injection. These include: stoichiometric ratio, injection temperature, sorbent pretreatment, sorbent particle size, and the mode of injection.

Buell, a division of Envirotech Corporation, has recently completed EPA-funded dry injection testing at the City of Colorado Springs' Martin Drake Station. The tests were begun in late October 1979 and completed in May 1980. Experiments with three sorbents, nahcolite, raw trona and refined trona were conducted on the 4500 acfm dry injection baghouse system.[7] The sorbents were ground to less than 74μm in diameter before being injected into the duct leading to the fabric filter. These tests were performed in an attempt to characterize the effects of sorbent type, stoichiometric ratio, temperature, and air-to-cloth ratio on SO_2 removal.

The results of these parametric tests, which are presented in Figures 2-9, 2-10, and 2-11, showed that nahcolite provided the best SO_2 removal followed by refined trona. Raw trona exhibited the weakest SO_2 removal capability. It was also found that an increase in the stoichiometric ratio caused SO_2 removal to increase. However, removal began to level off at stoichiometric ratios between 1.5 and 1.75 for these sodium sorbents. The effects of changes in temperature were also characterized. It was found that SO_2 removal decreased with increasing temperature for both nahcolite and refined trona. However, removal with raw trona increased with increasing temperature. (See Figures 2-9, 2-10, and 2-11.) Results of tests characterizing the effect of air-to-cloth ratio have shown that variation of the air-to-cloth ratio from 1.5 to 3.0 ft/min had no noticeable effect upon SO_2 removal.

TABLE 2-6. CURRENT DRY INJECTION PROGRAMS

Vendor	Location	Size	Comments
EPA/Buell-Envirotech	Colorado Springs - Martin Drake Station	4500 acfm	Testing completed in May 1980. EPA funded.
DOE/Grand Forks Energy Technology Center	GFETC Labs	200 acfm	Testing complete. Report is being prepared.
DOE/Pittsburgh Energy Technology Center	PETC Labs	500 lb coal/hr furnace	Testing completed. Report is in preparation.
EPRI/KVB	Public Service Company of Colorado - Cameo Station	20MWe	Testing in progress. Report on initial testing is expected in June 1981.

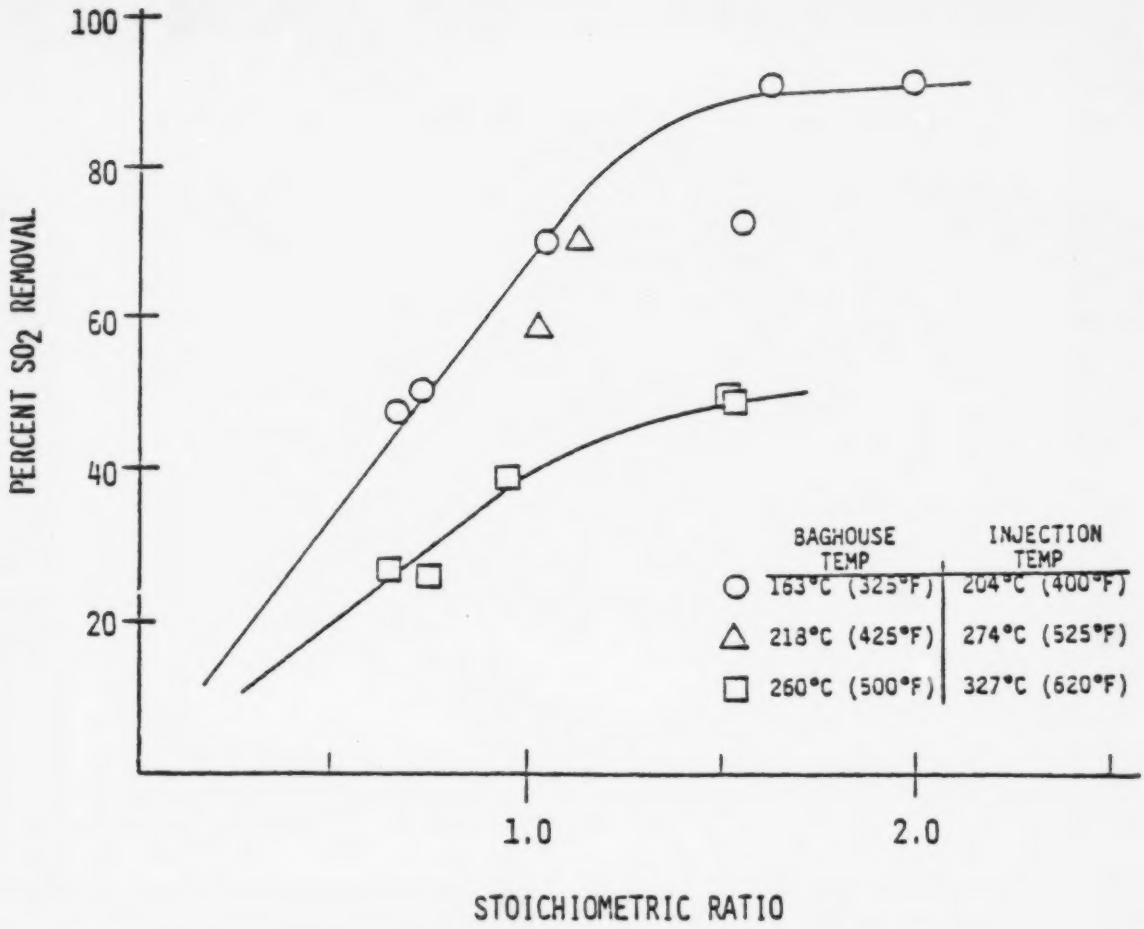

Figure 2-9. Dry injection with nahcolite (Buell data from Martin Drake Station).

Source: Parsons, Edward L., et al. (Reference 7).

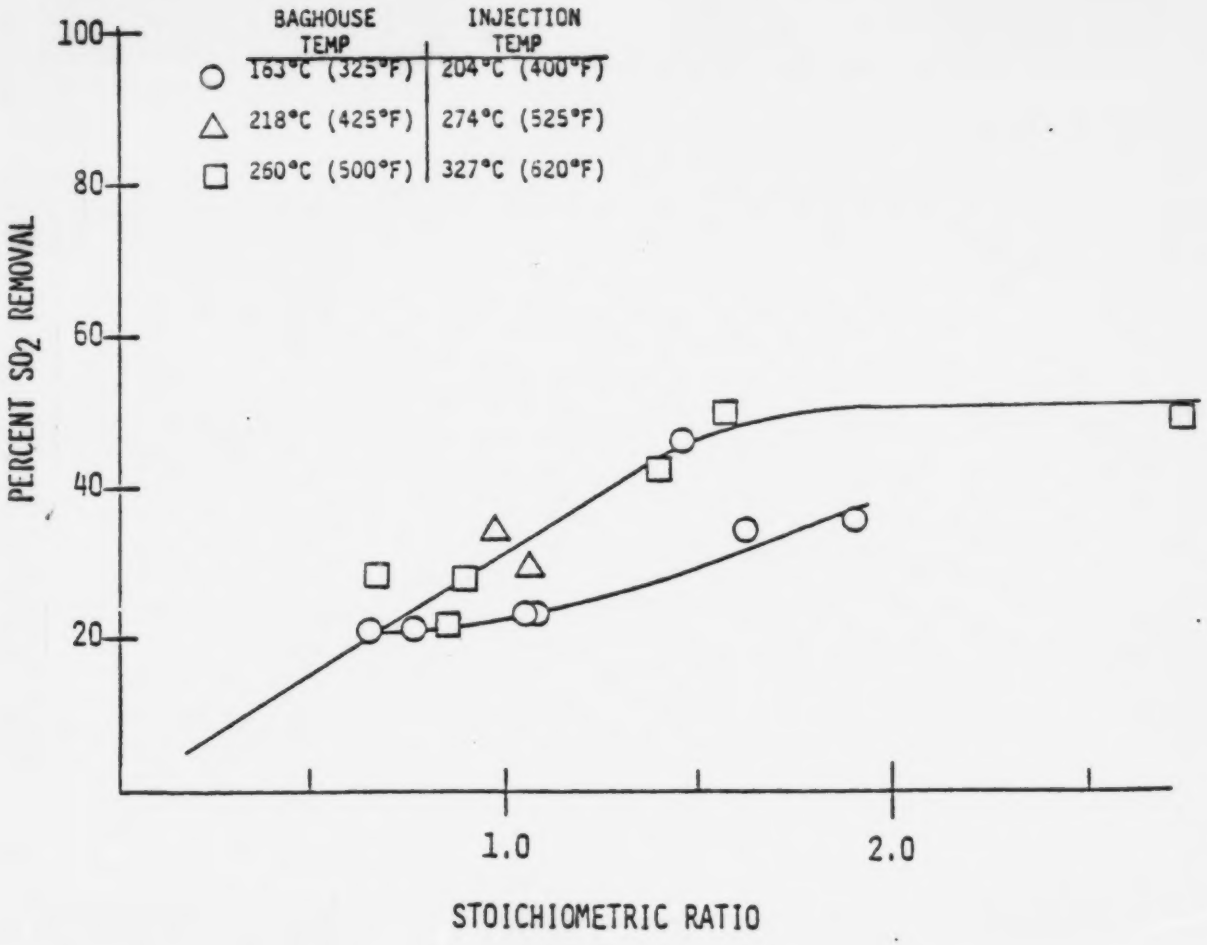

Figure 2-10. Dry injection with raw trona (Buell data from Martin Drake Station).

Source: Parsons, Edward L., et al. (Reference 7).

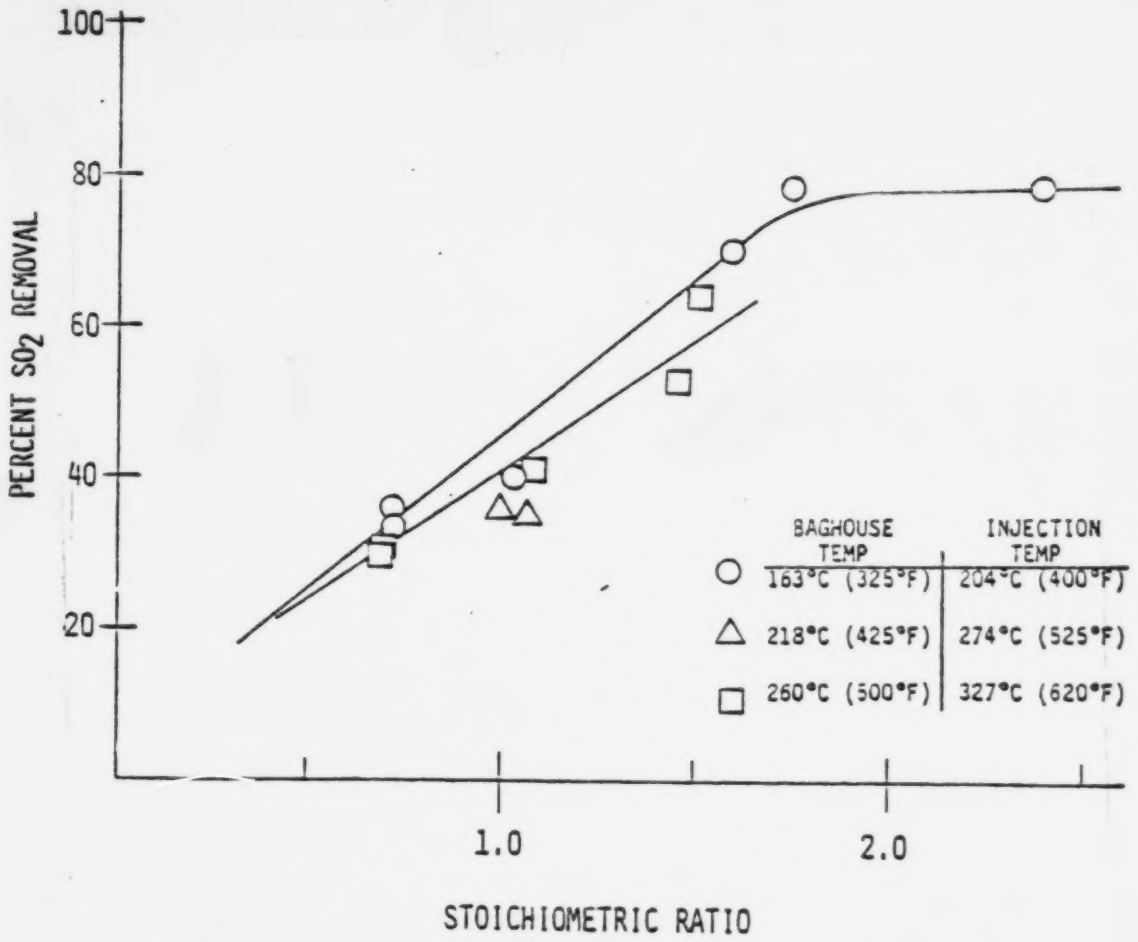

Figure 2-11. Dry injection with refined trona (Buell data from Martin Drake Station).

Source: Parsons, Edward L., et al. (Reference 7).

The DOE has conducted research on dry injection systems at both the Grand Forks Energy Technology Center (GFETC) and Pittsburgh Energy Technology Center (PETC). These tests have been performed in order to characterize several process parameters, such as sorbent type, inlet SO_2 concentration, inlet gas temperature, bag materials and air-to-cloth ratios.

Work conducted at GFETC with a 200-scfm dry injection system has shown that up to 90 percent utilization (based on NO_x and SO_2) has been obtained with trona and nahcolite sorbents. Low sulfur western coals were used in these tests, which resulted in inlet SO_2 concentration of 650 to 1100 ppm. The results reported here are preliminary; a final report on these tests has not been published yet.

GFETC has just completed the installation of a new 130-scfm pulse jet baghouse. This baghouse will be used exclusively for dry injection studies (the present baghouse was also used for particulate characterization studies.) Parametric tests with both nahcolite and trona will be conducted.

Dry injection work at the Pittsburgh Energy Technology Center (PETC) was completed in the Fall of 1980. A final report on the dry injection studies, which evaluated the performance of nahcolite, trona, and commercial sodium bicarbonate, is in preparation. The average baghouse temperature for the dry injection tests was 400°F. The fabric filter was equipped with Nomex bags and was operated at an air-to-cloth ratio of 4 ft/min. In general, the tests indicated that nahcolite showed the greatest SO_2 removal capability of the three sorbents evaluated.

In tests conducted with 1.1, 1.6 and 3.5 percent coals, dry injection of nahcolite resulted in SO_2 removals of up to 95 percent with a stoichiometric ratio of 1.5 moles Na_2O per mole of inlet sulfur. The tests also indicated that SO_2 removal decreased as inlet SO_2 concentration increased. However, 90 percent SO_2 removal was reportedly achieved with a stoichiometric ratio of 1.5, even when 3.5 percent sulfur coal was burned.

EPRI's Air Quality Control Program is conducting research on the technical aspects of a dry injection/baghouse system. Detailed laboratory scale tests have been completed. The results of these tests were summarized in the Second Survey of Dry SO_2 Control Systems. EPRI has been conducting large-scale dry injection tests at the Public Service of Colorado's Cameo Station since the Fall of 1980. These tests are being performed by KVB, Inc. on the 22 MWe Unit 1 boiler at Cameo using the existing fabric filter. Although no results are currently available for publication, the first phase testing with nahcolite has been completed and a final report is scheduled for June. Further testing will continue through the end of 1981.

2.4 COMBUSTION OF COAL/ALKALI FUEL MIXTURES

As discussed earlier, there are two processes being developed which are based on the combustion of coal/alkali fuel mixtures to control SO_2

emissions: combustion of a coal/limestone pellet in an industrial stoker-fired boiler and combustion of a pulverized coal/alkali fuel mixture in a low NO_x burner.

Recent large-scale test work with a 3.5:1 calcium to sulfur molar ratio coal/limestone pellet demonstrated that 50 percent SO_2 removal was achievable with this technology. Although earlier laboratory tests had indicated that SO_2 removals of up to 75 percent were possible, the higher, less controllable bed temperatures in the full-size industrial test unit (60,000 lb steam/hr) resulted in lower removal efficiencies. Inadequacies in the pellet production process have hampered development and progress in recent months, but EPA hopes to resolve these problems in the near future. Meanwhile, Battelle-Columbus Laboratories is continuing to test the properties and SO_2 removal capabilities of the pellets on a smaller scale (25,000 lb steam/hr boiler.)

The DOE and EPA have proposed a jointly funded 5-year development program to further investigate the concept of firing a coal/alkali fuel mixture in a low-NO_x burner. SO_2 removals of 50 percent and greater have been demonstrated on small-scale test work.

Reasons behind the accelerated development of both these technologies include the potential cost savings offered by reduced equipment requirements relative to conventional wet FGD and the retrofit potential of the technology for existing boilers.

2.5 REFERENCES

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3. Drabkin, Marvin, and Ernest Robison. Spray Dryer FGD Capital and Operating Cost Estimates for a Northeastern Utility. (Presented at EPA's Sixth FGD Symposium. Houston, Texas. October 28-31, 1980.) Mitre Corporation. McLean, Virginia.

4. Ahman, Stefan, et al. Flakt's Dry FGD Technology: Capabilities and Experience. Flakt, Inc. Old Greenwich, Connecticut. October 1980.

5. Downs, W., W.J. Sanders, and C.E. Miller. Control of SO_2 Emissions by Dry Scrubbing. (Presented at the American Power Conference. Chicago, Illinois. April 21-23, 1980.) Babcock & Wilcox. Barberton, Ohio.

6. Hurst, T.B. and G.T. Bielawski. Dry Scrubber Demonstration Plant - Operating Results. (Presented at EPA's Sixth FGD Symposium. Houston, Texas. October 28-31, 1980.) Babcock & Wilcox. Barberton, Ohio.

7. Parsons, Edward L., et al. SO_2 Removal by Dry FGD. (Presented at EPA's Sixth FGD Symposium. Houston, Texas. October 28-31, 1980.) Buell Emission Control Division. Lebanon, Pennsylvania.

8. Stevens, Nicholas, J. Dry Scrubbing Pilot Test Results. (Presented at EPA's Sixth FGD Symposium. Houston, Texas. October 28-31, 1980.) Research-Cottrell. Somerville, New Jersey.

SECTION 3

CURRENT AND RECENTLY COMPLETED ACTIVITIES

This section reports the pertinent activities of private companies and government or other agencies involved in the development of dry FGD systems. Included here are descriptions of current and recently completed research and development activities and information on commercial systems sold or being marketed.

The discussions are presented in alphabetical order by company or agency name. Much of the information has been obtained through personal contact or recently published papers. Some of the information from private companies is necessarily incomplete and, therefore, names of the company representatives who may be contacted for additional information on their firm's dry FGD activities have been provided.

3.1 BABCOCK AND WILCOX

Address: Babcock and Wilcox
20 South Van Buren
Barberton, Ohio 44023

Babcock and Wilcox
Alliance Laboratory
P.O. Box 834
Alliance, Ohio 44601

Contact for More Information:

Tom Hurst
Fossil Power Generation Division
Barberton, Ohio
(216) 753-4511

Cecil Miller
Fossil Power Generation Division
Barberton, Ohio
(216) 753-4511

William Downs
Alliance Laboratories
(216) 821-9110

Background Information

Babcock & Wilcox (B&W) has sold two utility spray drying systems: one to Basin Electric for the utility's Laramie River Station Unit 3 and one for Colorado Ute Power Company's Craig Station Unit 3. The B&W spray dryer system is based on the use of a horizontal reactor equipped with "Y-jet" spray nozzles adapted from B&W's standard oil burner technology. The Laramie River System will include an ESP, rather than a fabric filter, for particulate collection. B&W favors ESPs over fabric filters

for their spray drying systems. However depending on purchaser requirements or site specific conditions, they will substitute a fabric filter for the precipitator. In fact, the Craig Station system will have a fabric filter at the Colorado Ute's request.

A relatively large-scale (120,000 acfm spray dryer) demonstration program was recently completed by B&W at Pacific Power and Light's Jim Bridger Station. Meanwhile, B&W conducts fundamental research at their Alliance Research Center (ARC) laboratories.

Research and Development

Results of the now complete demonstration testing at Pacific Power and Light's Jim Bridger Station were presented at EPA's October FGD Symposium in Houston. (See Information Sources below.) Highlights of these results are summarized below.

The spray drying demonstration unit at the Jim Bridger Station included a 120,000 acfm horizontal flow spray reactor, which utilized dual fluid atomization, a 3000 acfm pilot fabric filter, and a 6000 acfm pilot ESP. Lime slurry testing with the unit was begun in November, 1979. Some of the objectives of the testing were to: 1) demonstrate on a large scale the operation of a multiple atomizer reactor, 2) demonstrate equipment reliability and performance, and 3) to confirm performance parameters measured previously in pilot testing. The unit operated for over 1750 hours.

A few modifications in the original spray reactor design were made to eliminate unexpected wear problems. The major change involved the medium used to atomize the slurry. The initial configuration used steam and, although steam produced good atomization, it also led to the rapid buildup of calcium deposits. Therefore, the atomizing medium was converted from steam to compressed air.

Analyses of several process parameters (stoichiometric ratio, approach to saturation temperature at the spray dryer outlet, fabric filter performance versus ESP performance, and the influence of fly ash alkalinity on SO_2 removal) were also performed. These analyses confirmed results obtained from previous pilot scale tests. The stoichiometric ratio was identified as the most important parameter. As the lime to SO_2 stoichiometry increased, the SO_2 removal also increased. As can be seen from Figure 3-1, 70 percent removal of SO_2 was achieved at a stoichiometric ratio of 1.4, whereas 55 percent removal was obtained with a stoichiometric ratio of 0.8. These data were gathered at inlet SO_2 concentrations of 350 to 400 ppm and without solids recycle. In addition, tests were performed comparing the performance of an ESP with that of a fabric filter. The results of these tests, which are presented in Figure 3-2, show that both particulate collection devices gave about the same overall performance. The use of a collection device increased SO_2 removal by approximately 5 percent over the removal obtained with a spray reactor alone.

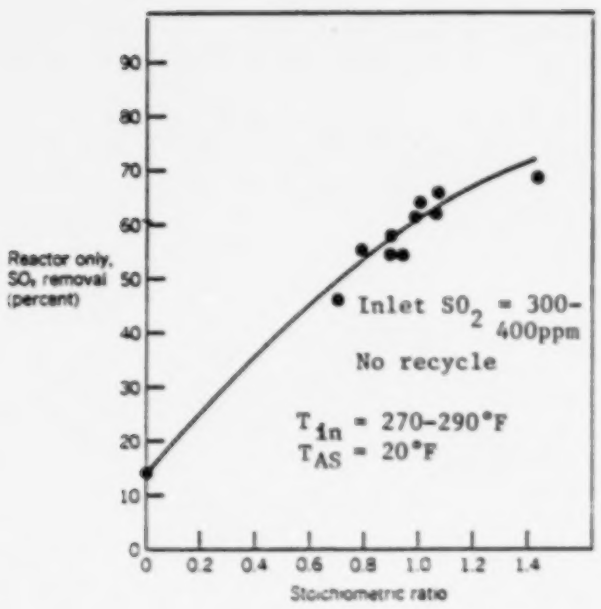
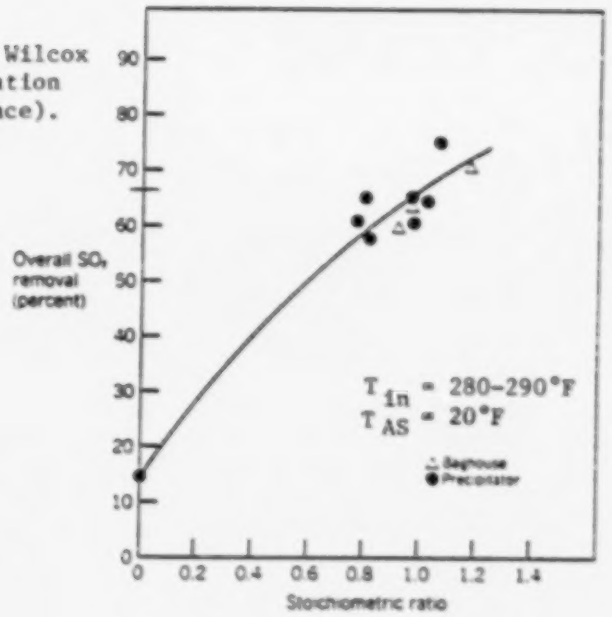


Figure 3-1. Babcock and Wilcox data from Jim Bridger Station (Reactor Performance Only).

Figure 3-2. Babcock and Wilcox data from Jim Bridger Station (Overall System Performance).

Source: Hurst, T.B. and G.T. Bielawski. (See Information Sources at the end of this section.)



Another parameter of importance is the approach to saturation temperature at the spray dryer outlet. In general, a closer approach to saturation will result in more moisture retention by the spray dried solids. Under identical operating conditions, it was found that a 30°F approach to saturation resulted in 65 percent overall removal, whereas 75 percent overall removal was achieved at a 20°F approach. These data verify the now widely demonstrated fact that better removal is obtained at a closer approach to saturation.

Tests were also performed in an attempt to characterize the effect of fly ash alkalinity on SO_2 removal. These tests indicated that up to 65 percent SO_2 removal could be obtained by spraying a slurry of high alkaline Laramie River coal ash alone. However, the quantity of ash was required to achieve this removal level was not specified.

The demonstration test results reportedly showed a high degree of reproducibility, and B&W will use this data as a basis for preparing commercial system bids. Basic research, as needed, is continuing only on an intermittent basis at the Alliance Research Center. The level and reliability of data previously gathered on this 1500 acfm unit is viewed by B&W as sufficient for the commercial system design process.

Babcock and Wilcox is not actively pursuing development of waste utilization schemes. The expertise of firms involved with wet sludge disposal is viewed by B&W as applicable to handling the dry scrubbing waste product.

Commercial Activities

Construction of both the Laramie River and Craig Station systems is on schedule, and both systems are expected to start-up on the previously announced dates: Spring 1982 for the Laramie River system and November 1982 for initial operation of the Craig Station system. Waste disposal at these sites does not appear to present any unusual problems. Both utilities will also have units equipped with wet FGD systems, and the dry waste may be combined with the wet sludge for disposal.

Information Sources

Miller, Cecil, Babcock and Wilcox. Telephone conversation with M.E. Kelly, Radian Corporation. January 27, 1980.

Hurst, T.B. and G.T. Bielawski. Dry Scrubber Demonstration Plant - Operating Results. (Presented at the Sixth EPA FGD Symposium. Houston, Texas. October 28-31, 1980.) Babcock and Wilcox. Barberton, Ohio. [Report on Jim Bridger demonstration program.]

3.2 BUELL/ANHYDRO AND EPA/BUELL

Address: Buell Emission Control Division
Envirotech Corporation
200 North Seventh Street
Lebanon, Pennsylvania 17042

U.S. Environmental Protection Agency
Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711

Contact for More Information:

Research Projects - Mr. Edward Parsons
Buell Emission Control Division
(717) 272-2001

Dr. T.G. Brna
EPA Project Officer
(919) 541-2683

Commercial Activities - Mr. Lloyd Hemenway
Buell Emission Control Division
(717) 272-2001

Background

Buell, a division of Envirotech Corporation, and the Danish spray dryer firm of Anhydro A/S are participating in development of both spray drying and dry injection systems and, in a joint venture are marketing a commercial spray drying system. Buell/Anhydro has conducted EPA-funded dry injection and spray drying demonstration testing at the City of Colorado Springs' Martin Drake Station. The dry injection work was started in late October 1979 and completed in 1980. The spray dryer/fabric filter tests began in early 1980 and are still underway. Test results of both programs have been published in various papers and were presented at the recent 1980 EPA-sponsored FGD Symposium.

In Fall 1980, the Buell/Anhydro joint venture was awarded a contract for a commercial spray drying system to serve a 44 MWe utility boiler at the Marquette (Michigan) Board of Light and Power's Shiras Municipal Power Plant.

Research and Development

During the first half of 1980, Buell/Anhydro conducted EPA-funded spray drying parametric optimization and performance tests and a 100-hr endurance test on the 20,000 acfm demonstration unit located at the City

of Colorado Springs' Martin Drake Station. The major results of this test work are discussed below. For more detail, see Information Sources at the end of this Section.

The spray dryer at the Martin Drake Station employs a centrifugal atomizer for slurry distribution and a top-entry vaned scroll-type gas disperser for mixing of the flue gas and slurry droplets. Pilot scale tests with a lime sorbent were conducted to optimize both equipment and process parameters. For their particular systems, Buell found that optimum SO_2 removal occurred with a centrifugal atomizer speed of 12,500 rpm, a gas disperser vane angle of 15° to 30° from the vertical, and a flue gas residence time in the spray dryer of 10 seconds.

Performance tests were also conducted to analyze the effect of several process parameters on SO_2 removal. The parameters which were investigated included stoichiometric ratio, approach to saturation temperature at the spray dryer outlet, and the effects of using off-product recycle. Results indicated that the stoichiometric ratio (SR) and the approach to saturation had the greatest impact on SO_2 removal. Figure 3-3 shows that SO_2 removal increases with increasing SR. At a constant approach to saturation of 20°F, SO_2 removal increased from 60 percent to 70 percent as the SR was increased from 0.8 to 1.2. Stochiometric ratios reported are in terms of moles of $Ca(OH)_2$ per mole of inlet SO_2. Figure 3-3 also shows that greater removal is obtained as the approach to saturation temperature at the spray dryer outlet is decreased. At a stoichiometric ratio of 1.0, SO_2 removal increased from 50 percent to 69 percent as the approach was decreased from 40°F to 20°F. Although better removal is obtained at a close approach to saturation temperature, Buell/Anhydro recommends that a minimum approach of 20°F be used to avoid equipment operation and maintenance problems. During the tests it was also observed that SO_2 removal in the baghouse was dependent upon the approach to saturation temperature, and the maximum SO_2 removal in the baghouse was obtained at lower approaches to saturation temperature.

The effect of using a partial recycle of the process off-product was also analyzed. Figure 3-4 indicates that recycling the off-product increased SO_2 removal by approximately 9 percent for given process conditions. It appeared that the increased removal resulted from the recovery of unutilized $Ca(OH)_2$ and $CaCO_3$ in the dried solids rather than from fly ash alkalinity. Two other process parameters which were investigated were the inlet SO_2 concentration and the flue gas temperature at the spray dryer inlet. It was found that changes in the inlet temperature had a negligible effect upon SO_2 removal. It was also observed that relatively constant SO_2 removal was obtained at inlet SO_2 concentrations of 1000 and 1500 ppm SO_2. However, removal fell off at SO_2 concentrations of 2000 and 2500 ppm SO_2.

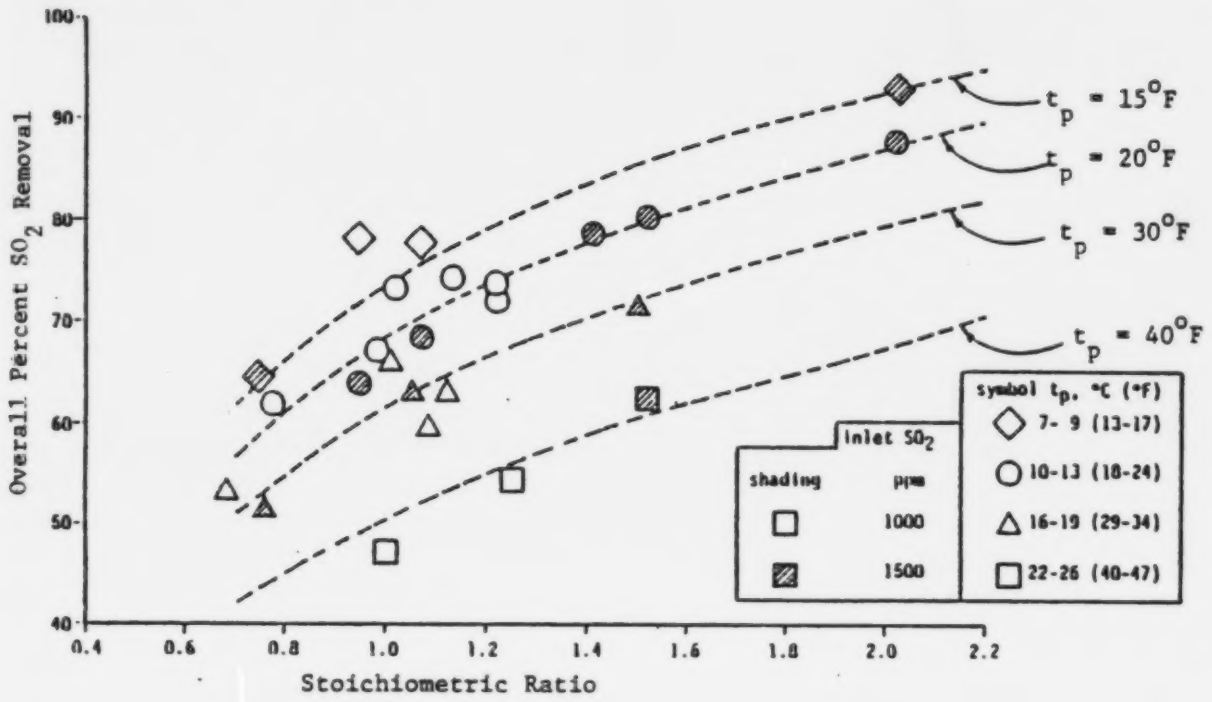


Figure 3-3. Effect of approach to adiabatic saturation temperature and stoichiometric ratio on spray dryer SO_2 removal. (Buell data from the Martin Drake Station).

Source: Parsons, Edward L., et al. (See Information Sources at the end of this section.)

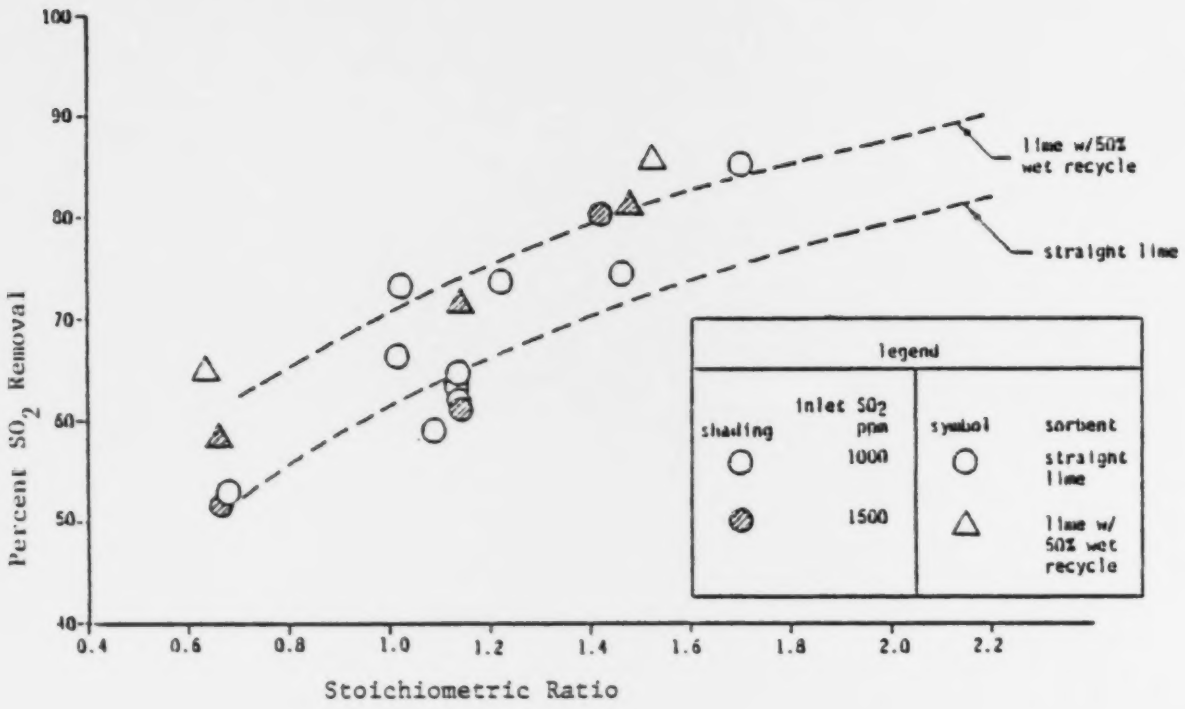


Figure 3-4. Effect of recycle on spray dryer SO_2 removal (Buell data from Martin Drake Station).

Source: Parsons, Edward L. et al. (See Information Sources at the end of this section.)

Spray drying tests were also conducted with two other sorbents: trona, and a mixture of limestone and adipic acid. The SO_2 removal obtained with trona was greater than that obtained with lime, but system performance with limestone/adipic acid was significantly worse than with lime. At a stoichiometric ratio of 1.4 and an approach to saturation of 30°F, approximately 92 percent SO_2 removal was obtained with trona, while 74 percent removal was obtained with lime. Stoichiometric ratio for this comparison was defined as "equivalent weight of sorbent per equivalent weight of SO_2 in", and both tests were made on a straight-through basis (i.e., no recycle of product solids). SO_2 removal with the limestone/adipic acid slurry did not exceed 35 percent during straight-through tests, even at adipic acid concentrations of up to 1220 ppm.

Dry injection of sodium-based alkalis was also investigated by Buell in another EPA-funded test program at Martin Drake. The results of this test work is summarized below. Again, for more information refer to the Information Sources at the end of this section.

Three sodium-based sorbents were evaluated during these tests. The approximate carbonate/bicarbonate compositions of the sorbents tested were: nahcolite - 53 percent $NaHCO_3$ and 3.5 percent Na_2CO_3; raw trona - 26 percent $NaHCO_3$, 41 percent Na_2CO_3; refined trona -59 percent $NaHCO_3$ and 14 percent Na_2CO_3. All three sorbents were ground to 95 percent minus 200 mesh (less than 74 μm) prior to their injection into the 100-ft. duct leading to the 16-bag fabric filter. A series of forty-three parametric tests were performed with these three sorbents in an attempt to characterize the effects of sorbent type, stoichiometric ratio, temperature, and air-to-cloth ratio on SO_2 removal.

The results of these tests, which are presented in Figures 3-5, 3-6, and 3-7, showed that nahcolite provided the best SO_2 removal, followed by refined trona. Raw trona exhibited the weakest SO_2 removal capability. From these figures it can be seen that an increase in the stoichiometric ratio caused SO_2 removal to increase. However, the removal began to level off at stoichiometric ratios between 1.5 and 1.75 for these sodium sorbents. (The units of the stoichiometric ratio were not reported, but were probably based on moles Na_2O to moles inlet SO_2.)

The effect of changes in the injection temperature (from 400° to 620°F) and the baghouse temperature (from 325° to 500°F) can also be seen from Figures 3-5, 3-6, and 3-7. For nahcolite and refined trona, SO_2 removal decreased with increasing temperature. However, removal with raw trona increased with increasing temperature. The reasons for this difference are unclear.

It was also found that variation of the air-to-cloth ratio from 1.5 to 3.0 ft/min had no noticeable effect upon SO_2 removal at given process conditions.

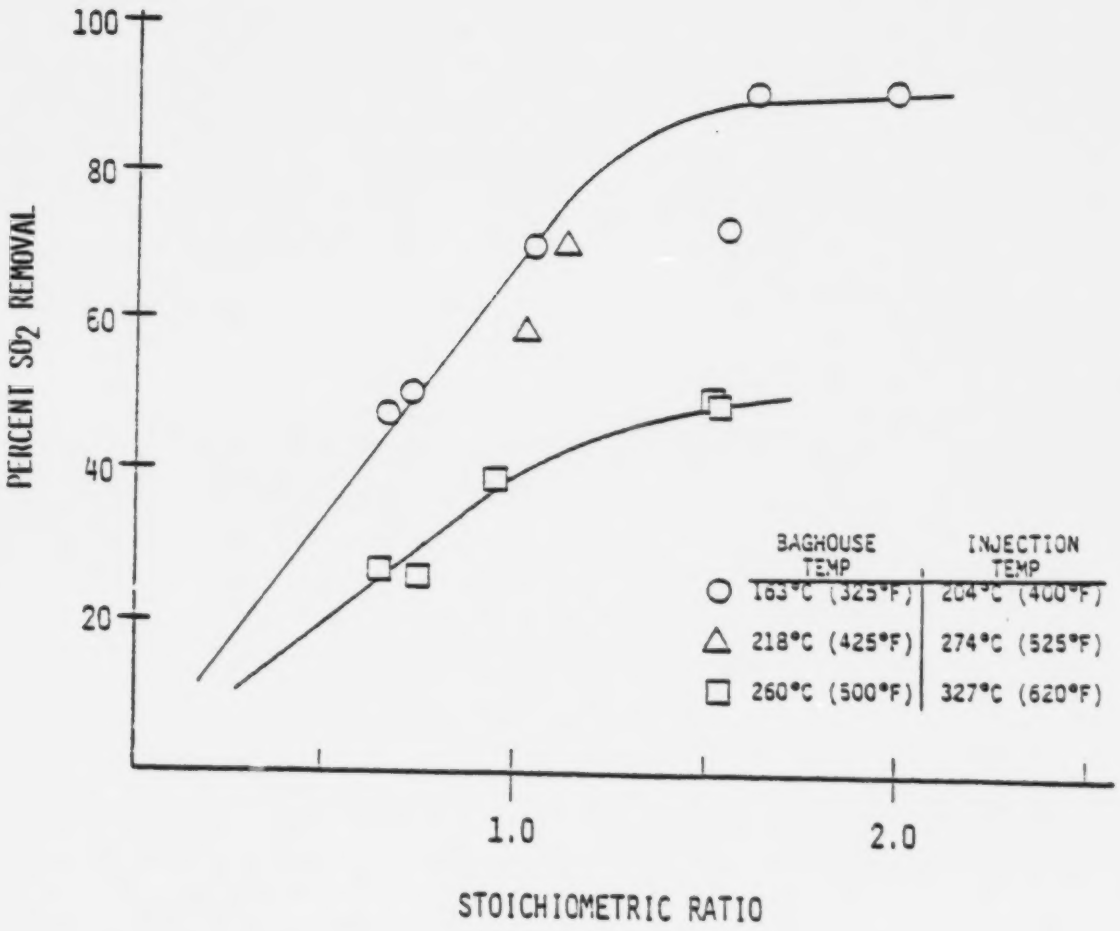


Figure 3-5. Dry injection with nahcolite (Buell data from Martin Drake Station).

Source: Parsons, Edward L., et al. (See Information Sources at the end of this section.)

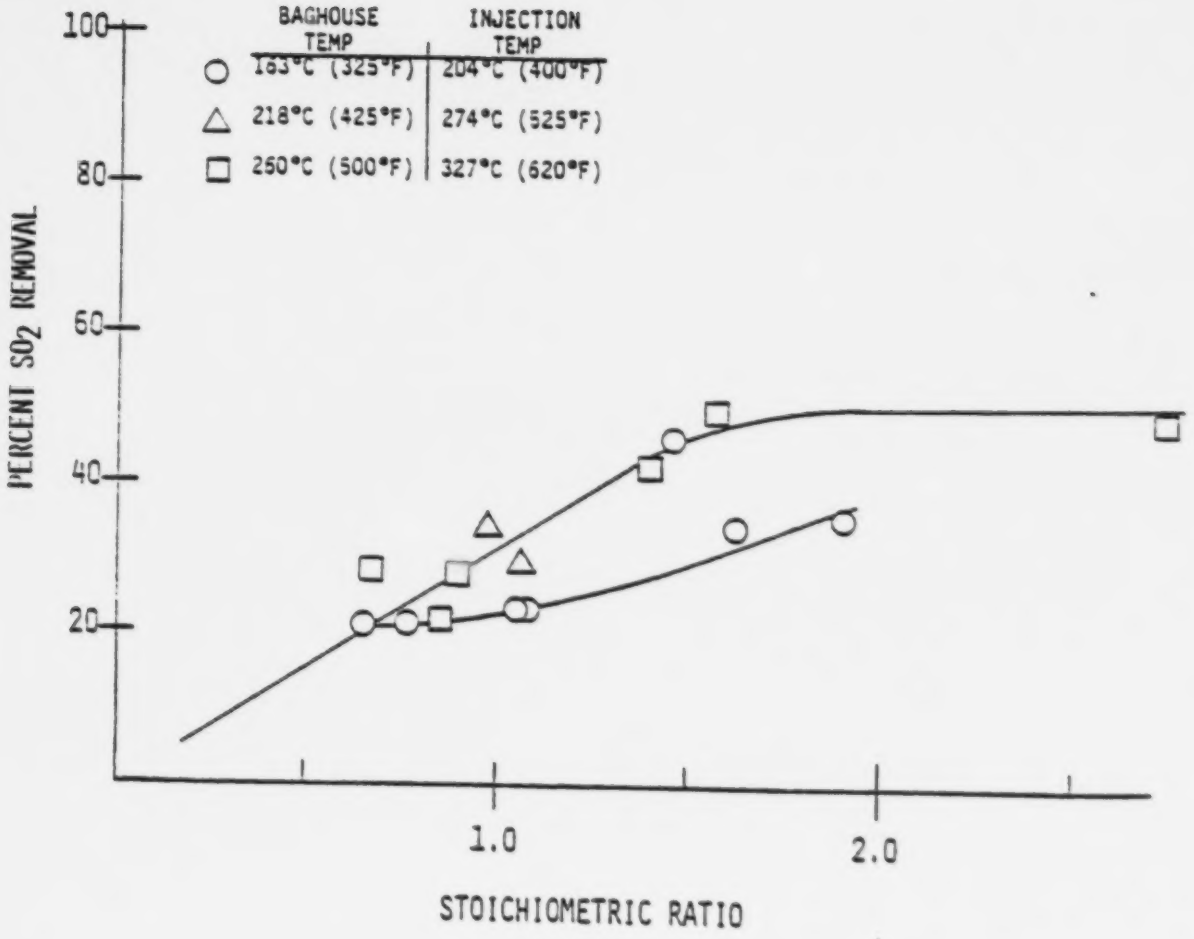


Figure 3-6. Dry injection with raw trona (Buell data from Martin Drake Station).

Source: Parsons, Edward L., et al. (See Information Sources at the end of this section.)

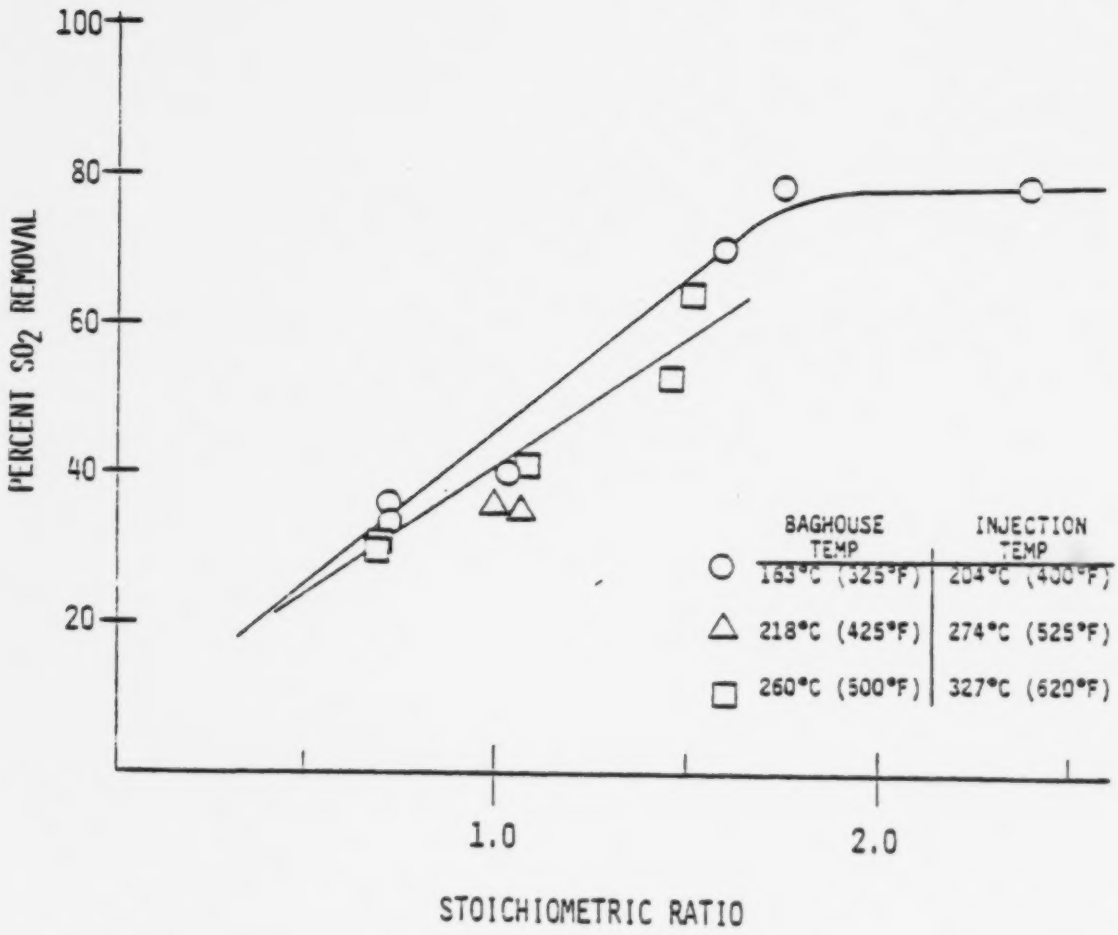


Figure 3-7. Dry injection with refined trona (Buell data from Martin Drake Station).

Source: Parsons, Edward L., et al. (See Information Sources at the end of this section.)

Buell/Anhydro is continuing to operate the spray dryer/fabric filter demonstration unit at Martin Drake. Test work since August 1980 has included runs with limestone (with adipic acid addition), trona, dolomitic lime, flue gas prequench upstream of the spray dryer, hot gas bypass for reheat, and dry injection of lignite fly ash upstream of the spray dryer. Detailed results of this test work will be presented at EPA's upcoming Particulate Control Symposium, scheduled for March 1981 in Orlando, Florida.

The purpose of the limestone/adipic acid tests was to determine the SO_2 removal achievable with limestone and to characterize the effects of adipic acid, off-product recycle, and different limestone grinds. The highest SO_2 removal achieved was 47 percent (at an inlet SO_2 concentration of about 1000 ppm). Most of the runs averaged between 20 and 30 percent SO_2 removal at stoichiometric ratios between 1.5 and 3.0 moles of CaO per mole of inlet SO_2. The SO_2 removal was found to be affected only slightly by the adipic acid concentration in the slurry, with removals slightly higher at increased concentrations.

In several test runs with trona, it was observed that the gas temperature at the dryer outlet had to be maintained at more than 20°F above the adiabatic saturation temperature of the gas to avoid wet product solids. The restriction on a closer approach (i.e., 20°F) to saturation with trona sorbent is attributed to the hygroscopic nature of the sodium-based product solids, relative the calcium-based product solids. Even with this restriction on approach to saturation, however, trona exhibited higher SO_2 removals and better sorbent utilization than lime at given process conditions of stochiometric ratio, inlet SO_2, and temperature drop over the dryer.

Tests were also run using a specially processed soft-burned dolomitic lime. The soft-burned lime, supplied by Warner Lime Co., has about an equimolar ratio of magnesium to calcuim availability. Conventional lime calcining fuses the magnesium compounds into glassy, non-porous structures, thus reducing the availability of magnesium for reaction with SO_2. In the lower temperature soft burning process, however, the magnesium compounds are not fused and can theoretically contribute to the SO_2 removal capability of the lime. Results of the tests made to date show the performance of soft-burned dolomitic lime to be equivalent to that of high calcium lime. However, there are certain factors that may require modification of spray dryer system design and operating conditions if dolomitic lime is to be used. First, the hygroscopic nature of the magnesium compounds requires that the approach to saturation at the dryer outlet be at least 30°F, although a longer gas residence time in the dryer may get around this restriction. Test results indicate that at a 30°F approach to saturation, the required stochiometric ratio for a given SO_2 removal and inlet SO_2 concentration is about the same for soft-burned dolomitic and high calcium lime. Secondly, slaking water temperature must be at least 170°F for dolomitic lime, and a longer

slurry residence time in the slaker is required. Finally, the thixotropic nature of the dolomitic lime slurry requires that a more powerful mixer be used in the slurry tanks.

In other tests, a spray system was installed upstream of the spray dryer to investigate the effects of partial gas prequench on spray dryer performance. It was thought that the increase in initial contact time during the constant rate stage (the increased contact time resulting from reduced gas velocity through the dryer) would increase SO_2 removal. It turned out, however, that this effect was balanced by the reduced available temperature drop across the dryer, and no significant increase in SO_2 removal was observed during the prequench tests.

In some test runs, dry lignite fly ash was pnuematically injected into the duct upstream of the dryer. The purpose of these tests was to demonstrate the effect of available alkalinity in the fly ash. Results showed that the fly ash alkalinity contributed markedly to increased SO_2 removal, but only when recycle of product solids was used. In tests without recycle, no increase in SO_2 removal was observed. These results suggest the importance of the aqueous phase reactions that occur in the spray dryer.

Future tests at Martin Drake will further evaluate the use of hot gas bypass and the use of cooling tower blowdown as recycle slurry water.

Buell has also conducted laboratory physical and chemical characterization tests on the waste solids generated during the lime spray drying runs at Martin Drake. Chemico, another division of Envirotech, conducted studies to determine various physical and chemical properties of the waste solids mixed with varying amounts of water. A mixture of 80 percent solids and 20 percent water displayed the most desireable properties in terms of disposal requirements. The unconfined compressive strength of the mixture was found to be about 12,000 lb/ft^2, and the permeability was less than 10^{-5} cm/sec. These values are similar to those for conventional fly ash-stabilized FGD sludges. The leachibility of heavy metallic compounds, as determined in the lab tests, was found to be well below the guidelines set by EPA for definition of a hazardous waste.

In other R&D activities, Buell is continuing to work with Anhydro at Anhydro's Copenhagen facility (a 3000 acfm spray dryer/fabric filter unit.) This permanent pilot unit will be used for basic research and development as well as for providing data needed to prepare specific commercial system bids.

Commercial Activities

Construction of the 44 MWe system at Marquette will begin in June 1981, with start-up scheduled for the Fall of 1982. The spray dryer/reverse-air fabric filter system will treat 226,000 acfm of flue gas from the Unit 3 pulverized coal-fired boiler in a 35 ft. diameter spray absorber, equipped with a single 200-hp rotary atomizer. The system design includes a paste (detention) slaker for the lime sorbent and a recycle system that will recycle waste solids from both the spray dryer and fabric filter. The recycle solids are slurried in a separate loop from the preparation of the fresh lime sorbent and mixed with the lime slurry flow just upstream of the atomizer.

Unit 3 will fire a nominal 1.5 percent sulfur western subbituminous coal that has a high heating value of about 7700 Btu/lb. Design SO_2 removal efficiency is 80 percent, and the design stochiometric ratio (with recycle) is 1.4 moles lime per mole of inlet SO_2. The flue gas temperature at the dryer inlet will range from 227 to 265°F.

The reverse-air fabric filter is designed for a maximum air-to-cloth ratio of 1.98:1 with one compartment off-line for cleaning. The unit will have woven fiberglass bags with an acid-resistant coating.

Buell/Anhydro is currently preparing bids for three utility systems, and they are involved in the final stages of consideration on a bid for a high sulfur coal-fired industrial boiler.

Information Sources

Parsons, Edward L., Buell. Telephone conversation with M.E. Kelly, Radian Corporation. January 14, 1981.

Parsons, Edward L., et al. SO_2 Removal by Dry FGD. (Presented at the EPA Symposium on Flue Gas Desulfurization. Houston, Texas. October 28-31, 1980.) Buell Emission Control Division. Lebanon, Pennsylvania. [Report on Martin Drake Station test results.]

Envirotech Corporation. Air Quality Report: Buell Emission Control to build dry-process FGD system for Board of Light and Power, Marquette, Michigan. Letter and attachments from Renberg, Walter, Envirotech, to J.C. Dickerman, Radian Corporation. December 15, 1980.

3.3 COMBUSTION ENGINEERING

Address: Combustion Engineering, Inc.
P.O. Box 7462-A
Birmingham, Alabama 35223

Contact for More Information: Kal W. Malki
Environmental Systems Division
(205) 967-9120

Background

Combustion Engineering (C-E) began a pilot-plant research and development program in February 1979 at Northern States Power Company's Sherburne County Generating Station in Becker, Minesota. In this testing, the reactivity of alkaline fly ash constituents on additive stoichiometry and SO_2 removal was investigated.

Research and Development

The pilot study at Sherburne County indicated several areas that needed further investigation. C-E felt that optimization of design could only be realized through further development work. A second generation pilot-plant at Alabama Power Company's Gadsden plant began operation in January 1981. The tests, which are expected to continue through the year, will include full parametric testing. Only lime-based sorbents will be tested because C-E considers sodium sorbents to be too expensive for dry FGD applications. Initial tests at Gadsden will be with low to medium sulfur coal, with higher sulfur coal to be tested later. Studies on physical and chemical characteristics of dry scrubbing wastes will also be conducted. In addition, waste utilization schemes may also be developed.

Commercial Activities

C-E does not feel that dry scrubbing is applicable to high sulfur coals. They have limited their bids to low sulfur coal systems. At present C-E is not preparing any commercial system bids.

Information Source

Malki, Kal, C-E. Telephone Conversation with Syed Shareef, Radian Corporation. January 22, 1981.

3.4 DOE/GRAND FORKS ENERGY TECHNOLOGY CENTER

Address: Grand Forks Energy Technology Center
P.O. Box 8213
University Station
Grand Forks, North Dakota 58201

Contact for More Information: Harvey Ness
Grand Forks Energy Technology Center
(701) 795-8000

Background

Grand Forks Energy Technology Center (GFETC) has been conducting research on dry injection systems on a 200-scfm scale, comparing nahcolite and trona sorbents. Parameters investigated included inlet SO_2 concentration, inlet gas temperature, bag materials, air-to-cloth ratios, and the sequencing of sorbent addition and bag cleaning cycles.

Research and Development

Tentative results of the 200-scfm scale tests have shown close to 90 percent utilization (based on NO_x and SO_2) for both nahcolite and trona. These tests were performed on low sulfur western coals (650-1100 ppm inlet SO_2 concentration). A final report on these tests has not been published yet. In addition, a contract has been signed with an unidentified company to perform sodium recovery tests. The purpose of these tests, which began recently, is to determine the usefulness of reinjecting spent sorbent/fly ash into the dry injection system. Also, Radian Corporation is conducting a study on characterization and disposal of dry FGD waste under a contract with GFETC. (See Section 4 of this report.)

Future Research

The construction of a new 130-scfm pulse jet baghouse has not been completed. This baghouse will be used exclusively for dry injection studies (the present baghouse was also used for particulate characterization studies). Both trona and nahcolite will be tested while varying parameters such as temperature, residence time, air-to-cloth ratio, and sorbent stoichiometry. Tests will be conducted at temperatures up to 800°F.

In addition, GFETC will be involved with the spray dryer/fabric filter FGD System at Otter Tail Power's Coyote Station. GFETC will conduct a sampling and monitoring program to evaluate particulate and SO_2 removal efficiencies under typical operating conditions at Coyote Station.

Information Source

Ness, Harvey, GFETC. Telephone Conversation with Syed Shareef, Radian Corporation. January 7, 1981.

3.5 DOE/PITTSBURGH ENERGY TECHNOLOGY CENTER

Address: Pittsburgh Energy Technology Center
4800 Forbes Road
Pittsburgh, Pennsylvania 15213

Contact for More Information: Richard Demski
Pittsburgh Energy Technology Center
(412) 675-5730

Background

DOE's Pittsburgh Energy Technology Center (PETC) has conducted small pilot-scale research to evaluate both dry injection and, more recently, spray drying. A 500-lb/hr coal furnace generates flue gas for the test systems.

Research

The work at PETC is now focused only on spray drying, with the dry injection studies having been completed in the Fall of 1980. The PETC system consists of a 500 lb/hr coal furnace which generates about 2500 acfm of flue gas. A final report on the dry injection studies, which evaluated the performance of nahcolite, trona, and commercial sodium bicarbonate, is in preparation. In general, the tests indicated that of the three sorbents evaluated, nahcolite displayed the best performance with regard to SO_2 removal capability and sorbent utilization.

In tests conducted with 1.1, 1.6, and 3.5 percent sulfur coals, dry injection of nahcolite resulted in SO_2 removals of up to 95 percent with a stoichiometric ratio of 1.5 moles Na_2O per mole of inlet sulfur. The tests indicated that SO_2 removal decreased as inlet SO_2 concentration increased. However, 90 percent SO_2 removal was reportedly achieved with a stoichiometric ratio of 1.5 moles Na_2O per mole of inlet sulfur, even when the 3.5 percent sulfur coal was burned.

Two supposedly identical batches of trona exhibited different SO_2 removal levels at given process conditions; removal variations of up to 20 percent were observed in some cases. The results from tests with the two batches varied as shown below:

Trona Batch	SO_2 Removal (%)	Stochiometric Ratio (moles Na_2O per mole inlet S)
Batch 1	80%	1
	97.5%	3
Batch 2	55%	1
	90%	3

Part of the variation was attributed to possible differences in the ages of the two batches which may have affected sorbent reactivity.

The average flue gas temperature for the dry injection tests was 400°F. The fabric filter, equipped with Nomex bags, operated at an air-to-cloth ratio of 4 ft/min.

PETC will focus on high-sulfur coal testing in the upcoming spray drying test program. The test furnace will fire a 3-percent sulfur Pittsburgh seam coal. The spray dryer will be followed by the same fabric filter used in the dry injection tests and most runs will be conducted at a 20°F appraoch to saturation. The inlet flue gas temperature will be about 400°F. The tests will evaluate performance of lime, limestone, and nahcolite. The current system design does not include solids recycle capabilities, although this feature may be added next year.

Information Source

Demski, Richard, Pittsburgh Energy Technology Center. Telephone conversation with M.E. Kelly, Radian Corporation. January 3, 1981.

3.6 ECOLAIRE

Address: Ecolaire Systems, Inc.
380 Civic Drive
Pleasant Hill, California 94523

Contact for More Information: Jim Boyer
(415) 676-6315

Background

Ecolaire has constructed a mobile pilot plant for demonstration of a spray dryer/baghouse FGD system. The unit has an Ecolaire-modified Niro atomizer spray dryer and an ICA four-section baghouse with 12-in. diameter by 36-ft. length bags. The 10,000 cfm mobile demonstration unit (MDU) is currently installed on Unit No. 1 at the Gerald Gentleman Station of the Nebraska Public Power District at Sutherland, Nebraska.

Research and Development

Performance tests at Gerald Gentleman Station were conducted at inlet SO_2 concentrations ranging from 300 to 2,500 ppm. The factors studied included SO_2 removal efficiencies versus sorbent utilization, spray down temperatures, different inlet SO_2 concentrations, and effects of sorbent recycle and boiler turndown. In addition, performance of both rotary and nozzle atomizers was evaluated. Results of the tests are considered proprietary.

Commercial Activities

Ecolaire recently sold a commercial system to Container Corporation. The spray dryer/baghouse system will be installed at a plant in Philadelphia. The spray dryer will have a single rotary atomizer, and the baghouse will be a pulse-jet type. The 170,000 lb steam/hr boiler will burn 1 percent sulfur coal. The system will have provisions for solids recycle and will use lime as the sorbent. The construction of the FGD system is scheduled to begin in April, and start-up is expected to be in October 1981.

Information Source

Boyer, Jim. Ecolaire. Telephone Conversation with Syed Shareef, Radian Corporation. February 6, 1981.

3.7 ELECTRIC POWER RESEARCH INSTITUTE (EPRI)

Address: Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

Contact for More Information:

Spray Drying Activities - Dick Rhudy
EPRI Project Manager
(415) 855-2421

Dry Injection Activities - Richard Hooper
EPRI Project Manager
Arapahoe Office
(303) 936-7281

Background

EPRI's Air Quality Control Program is conducting several programs in the dry scrubbing area, including demonstration-scale testing of both dry injection and spray drying. Previously, EPRI has funded laboratory-scale dry injection tests.

Research and Development

EPRI currently has three spray drying-related programs:

- A solid waste study, contracted to Radian Corporation
- A survey of utility spray dryer systems, contracted to Stearns-Roger
- A spray drying demonstration program at Public Service of Colorado's Arapahoe Station, contracted to Stearns-Roger

The recently initiated solid waste study is intended to fully characterize the physical and chemical properties of solid waste from dry injection and spray drying systems. The physical and chemical tests will be run on twenty to thirty solid samples to provide comparative data concerning the effects of system design and coal type on the properties of the solids. The tests will focus on the physical and chemical characteristics which will impact the handling and disposal of the waste and will include the following:

- Solids morphology
- Elemental analysis
- X-ray diffraction compound analysis
- Moisture determination
- Acid and water insolubles
- Leaching tests
- Measurement of strength development
- Radioactivity

A final report is expected in the Fall of 1981. More details on this study can be found in Section 4.

To be published in Spring 1981, the Stearns-Roger survey was conducted by contacting the utilities who have purchased commercial systems. The survey covers the design and operating parameters of full-scale utility spray drying systems, including waste disposal plans.

EPRI's spray drying demonstration program at Public Service of Colorado's Arapahoe Station is scheduled to last from 6 months to a year once construction of the system is complete. Stork-Bowen will be responsible for the design and construction of the spray dryer, which will treat about 2½ MWe equivalent of flue gas. Sorbents to be tested include lime, limestone, and sodium-based compounds. The Arapahoe unit normally fires a 0.5 percent sulfur coal, resulting in about a 400 ppm SO_2 flue

gas. For higher inlet SO_2 testing, the flue gas will be spiked with SO_2 up to about 2000 ppm. The system will also include both a paste slaker and a ball mill slaker, flue gas bypass and solids recycle capabilities, and the option to use rotary or dual-fluid nozzle atomizers.

The tests, which will be parametrically oriented rather than endurance-type runs. Most of the tests will be run at a 20 to 25°F approach to saturation at the dryer outlet. Closer approaches may be used, depending on the effects on the downstream fabric filter and the degree of dryness of the waste solids exiting the dryer. Later testing with the system may focus on the control aspects of the spray drying process.

Large-scale dry injection demonstration tests have been in progress at Public Service of Colorado's Cameo Station since Fall 1980. The tests are being conducted by KVB, Inc. on the 22 MWe Unit 1 boiler at Cameo using the existing fabric filteAlthough no results are currently available for publication, the first phase testing with nahcolite has been completed and a final report is scheduled for publication in June. Testing will continue through the end of 1981.

Information Sources

Rhudy, Dick, EPRI. Telephone conversation with M.E. Kelly, Radian Corporation. January 13, 1981.

Hooper, Richard, EPRI. Telephone conversation with M.E. Kelly, Radian Corporation. January 26, 1981.

Radian Corporation. Proposal for EPRI Research Project RP-1870: Characterization of Spray Drying Wastes.

3.8 ENERGY AND POLLUTION CONTROL, INC.

Address: Energy and Pollution Controls, Inc.
Subsidiary of Flick-Reedy, Inc.
7N015 York Road
Bensenville, Illinois 60106

Contact for More Information: Grant Hollett, Jr.
Energy and Pollution Controls
(312) 766-3400

Background

Development work on the Energy and Pollution Control (EPC)-designed reactor was started in early 1978. This dry FGD reactor uses a hydraulically-driven "slinger" to distribute dry hydrated lime into the flue gas. The reactor is followed by a fabric filter for collection of the product solids.

Commerical Activities

EPC is concentrating its marketing efforts entirely on industrial applications. In May 1980, EPC ran a program of on-site pilot-scale tests for a customer in the brick manufacturing business. Based on the results of these tests, a preliminary design for a commercial-sized system has been completed. The design specifies four reactors, each of 25,000 acfm capacity. EPC's client has submitted the design to the EPA for approval. The sale of the system will be finalized after the financing arrangements have been made by the client. Meanwhile, EPC is continuing licensing negotiations for their dry FGD system with other companies.

Future Activities

EPC will be conducting tests in conjunction with ETS, Inc. of Roanoke, Virginia on a 60,000 lb/hr industrial boiler at the Kerr-Renrew finishing plant in South Carolina. These tests are scheduled to begin in January 1981 and will be performed at inlet flue gas SO_2 concentrations of 400 to 1,000 ppm. The initial tests will be with low sulfur coal with the subsequent tests on increasingly higher sulfur coals. A slipstream of 1,000 to 2,000 cfm will be used for test purposes. The system includes a baghouse following the EPC reactor and has provisions for recycling. The tests will be jointly funded by EPC and ETS, Inc.

Information Source

Hollett, Grant, EPC. Telephone Conversation with Syed A. Shareef, January 7, 1981.

3.9 EPA/BATTELLE-COLUMBUS LABORATORIES

Address: U.S. Environmental Protection Agency
Industrial Environmental Research Labs
Research Triangle Park, North Carolina 27711

Battelle-Columbus Laboratories
405 King Avenue
Columbus, Ohio 43201

Contact for More Information: J.H. Wasser
EPA Project Officer
(919) 541-2476

Robert Giammar
Battelle-Columbus Laboratories
(614) 424-7701

Background

Under EPA-funding, Battelle Columbus Laboratories has developed a coal/limestone pellet that is suitable for firing in industrial spreader stoker boilers to control SO_2 emissions. The most recent test work has been conducted with a pellet containing a 3.5:1 molar ratio of calcium to sulfur. The pellet was fired in a 25,000 lb steam/hr stoker boiler at the Columbus Laboratories' steam plant in December 1979. Sulfur capture (or retention) averaged 50 percent during these tests. Economic estimates indicate that the pellet can be produced for about $15/ton (not including the cost of coal).

Research and Development

Results of the tests on the 20,000 lb steam/hr steam plant stoker boiler were discussed in the Second Survey and were also presented at EPA's Sixth FGD Symposium in Houston (See Information Sources below.)

Based on these test results, and the continuing need for lower cost SO_2 control technologies for industrial boilers stemming from potential new source regulations and retrofit requirements, EPA scheduled a 14-day continuous test burn of the pellets. The tests were to be conducted on a 60,000 lb steam/hr chaingrate stoker boiler at the Indianapolis General Motors plant. Scheduled for November 1980, the continuous test was preceeded by an 8-hr burn of the pellets, during which sulfur retention averaged 50 percent. Although early laboratory tests had showed that 75 percent SO_2 removal was achievable with the 3.5:1 Ca:S pellet, the inability to control bed temperatures to the desired level (2300°F) resulted in lower SO_2 removal when the pellet was fired in the commercial unit.

The 14-day test has been delayed indefinitely due to problems with the pellets as manufactured by Banner Industries. Adequate drying of the pellets on a large-scale production basis has not been possible with Banner's existing process equipment. If pellets with the desired strength and dryness can be produced on a large scale, with modifications to existing equipment or with a new process, extended test runs may begin in the Spring of 1981 on the same General Motors unit. Meanwhile, Battelle will continue to conduct basic research on the 20,000 lb steam/hr stoker at the Columbus Laboratories' steam plant.

Information Sources

Wasser, J.H., EPA. Telephone conversation with M.E. Kelly, Radian Corporation. January 5, 1981.

Giammar, Robert D., et al. Evaluation of Emissions and Control Technology for Industrial Stoker Boilers. (Presented at EPA's Sixth FGD Symposium. Houston, Texas. October 28-31, 1980.) Battelle-Columbus Laboratories. Columbus, Ohio.

3.10 EPA/ENERGY AND ENVIRONMENTAL RESEARCH CORPORATION (EERC)

Address: U.S. Environmental Protection Agency
Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711

Contact for More Information: Blair Martin
EPA Project Director
(919) 541-2235

Background

EERC conducted a preliminary feasibility study as part of a program to test EPA's concept of alkali injection into a low-NO_x burner for SO_2 removal. In this process, the alkali (usually limestone or trona) is mixed and pulverized with coal prior to combustion and fired through a low-NO_x burner. Sulfur contained in the fuel reacts with the alkali present to form calcium- or sodium-based salts which are collected with the fly ash emitted from the boiler.

As a result of the favorable performance data from the initial tests, EPA decided to conduct tests on a range of combustor sizes: 70,000 Btu/hr, 1 million Btu/hr, 10 million Btu/hr, and 50 million Btu/hr.

Research and Development

Full parametric testing is in progress on the 70,000 Btu/hr bench-scale unit. Tests are being conducted on a low sulfur Utah coal (0.7% S) and a German brown coal (0.35% S as received). The coals are similar in nature with respect to combustion characteristics. Results of the tests will not be available for another three months.

The mid-sized, 1 million Btu/hr unit has been constructed. Testing will be completed on both the units over the next 9- to 12 month-period. Tests will then begin in the larger (10 million Btu/hr and 50 million Btu/hr) units.

Future Activities

An agreement has recently been reached between the EPA and the Department of Energy to provide joint funding for a 5-year program on NO_x and SO_x control by sorbent injection through low-NO_x coal burners. The primary emphasis will be on the retrofit of existing boilers for control of acid rain precursors. However, the studies should also provide on assessment of the potential of the technology for new boilers specifically designed for optimum NO_x and SO_x control. The retrofit goal is to equal or exceed 50 percent SO_x removal at alkali metal-to-sulfur stoichiometries of less than 2. The research will also indicate the maximum level of control achievable under optimum conditions with a research goal of 90 percent SO_x removal and NO_x emissions below 130 ng/J (0.3 lb per million Btu).

The details of the program will be available after internal government review. Part of this work is to be performed by EERC. Over the next year and a half, contracts will be awarded for other parts of the project. Some contracts in the developmental area are expected this spring, and more in-field evaluation work will be awarded next winter.

Information Sources

Blair Martin, EPA. Telephone conversation with Syed Shareef, Radian Corporation. January 7, 1981.

NO_x Control Review, EPA-IERL, Research Triangle Park, North Carolina. Fall 1980.

3.11 FLAKT, INC.

Address: Flakt, Inc.
1500 East Putnam Avenue
Old Greenwich, Connecticut 06870

Contact for More Information: James Farrington
Product Manager
Gas Absorption Systems
(203) 637-5401

Background

Flakt's capabilities in the dry FGD area are based on experience in four allied technologies: conditioning towers and atomization, dust collection, wet FGD processes, and dry adsorption. With the experience gained from these allied technologies, Flakt initiated its dry FGD development program in 1978.

Flakt has two pilot plant programs, one in Denmark and one at Pacific Power & Light's Jim Bridger Station.

Research and Development

A 10,000 acfm pilot unit has operated since January 1980 at the Asnaes Power Station in Kalundburg, Denmark. Coal is imported from different sources and the quality of the coal varies over a wide range. The Flakt pilot plant was, therefore, designed with sufficient flexibility to allow efficient operation for varying coal sources. The FGD system takes a slipstream of 10,000 acfm which can either pass through a cyclone where a major portion of the fly ash is collected or be fed directly into the SO_2 reactor where the absorbent lime slurry is sprayed into the hot flue gas by means of a dual-fluid nozzle. Before the gas is returned to the main flue gas duct, it passes through a fabric filter where the fly ash and reaction products are collected. Flakt has reported that a significant portion of the total SO_2 absorption occurs in the fabric filter where the SO_2 contacts the dust deposited on the bags.

The coal types tested so far at Asnaes ranged in heating value from 9,520 Btu/lb to 10,955 Btu/lb. The ash content varied from 14.7 to 23.3 percent, while the sulfur content ranged from 0.3 to 1.2 percent. The sulfur content of the coals corresponds to 500-1250 ppm inlet SO_2. The fly ash alkalinity of the coals varied between 0.08 and 0.72 moles/mole SO_2 (defined as fly ash alkalinity, based on titration with sulfuric acid, in flue gas entering reactor per mole of SO_2 entering reactor). Within the range of the coals studied, results from the once-through operations (without recycle) were found to be very uniform despite different SO_2 contents, fly ash alkalinity, etc. This indicates that in this mode of operation the contribution from the fly ash alkalinity to SO_2 absorption was marginal. Only minor changes in SO_2 removal efficiency were recorded when switching from operation with the fly ash pre-collector to without it, which further verified that the SO_2 reactive alkalinity was essentially derived from the sorbent. However, at low stoichiometries (0.5) sorbent utilization was about 100 percent, which demonstrates that the ash in these cases (i.e., low stoichiometry cases) contributed to the SO_2 removal. When firing a certain type of Polish coal and spraying only water into the reactor, SO_2 removal efficiency was found to be 12 percent.

The Jim Bridger Station, a 2,000 MWe generating station jointly owned by Pacific Power and Light Company and Idaho Power Company, is the site of Flakt's other dry FGD pilot program. Tests have been in progress since March 1980. This facility uses a sub-bitumminous coal with an average heating value of 9,600 Btu/lb, ash content of 10 percent, and an average sulfur content of 0.6 percent. The pilot plant includes two alternative reactor configurations, a vertical and a horizontal tower reactor. Also, both a three-field ESP and a fabric filter are available for particulate collection.

Testing at the Jim Bridger pilot plant was performed from March to September 1980. The initial test plan included eight test blocks which consisted of short-term parametric tests and long-term reliability runs.

The results at Jim Bridger showed that SO_2 removal efficiency improves as the reactor outlet gas temperature approaches the wet bulb temperature (Figure 3-8). The tests showed that the practical limit for operation with soda ash was for the reactor outlet gas to be 20°F above saturation temperature. Another operating parameter which significantly affected SO_2 removal efficiency was the alkali stoichiometric ratio (based on inlet SO_2). The SO_2 removal was found to be higher for higher alkali input. It was also observed that SO_2 removal efficiency deteriorated as the inlet SO_2 concentration increased for the same stoichiometric ratio. Sodium was found to be more reactive than calcium (lime). However, it was found that soda liquor and its reaction products were slightly more difficult to dry, as the atomizer droplet size increased. By monitoring small enough droplets (approximately 50-microns diameter) it was possible to achieve the efficiencies reported (Figures 3-8 and 3-9). Further, by increasing the inlet flue gas temperature, SO_2 removal efficiency was increased as a result of the increased temperature drop available over the spray dryer.

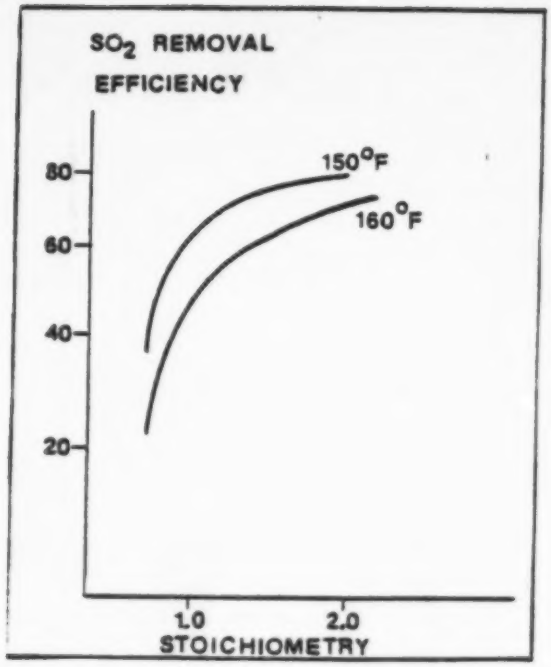


Figure 3-8. SO_2 removal performance at different outlet temperatures, reactor only (Alkali: Sodium Carbonate).

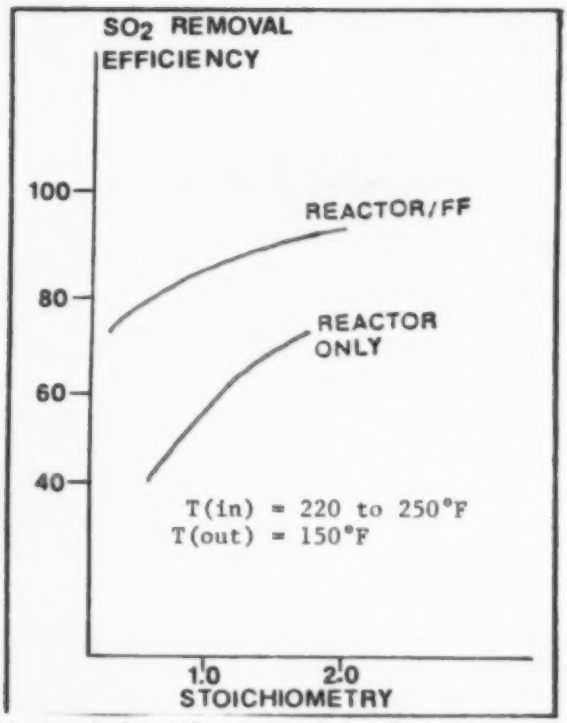


Figure 3-9. SO_2 removal performance, reactor/fabric filter (Alkali: Sodium Carbonate).

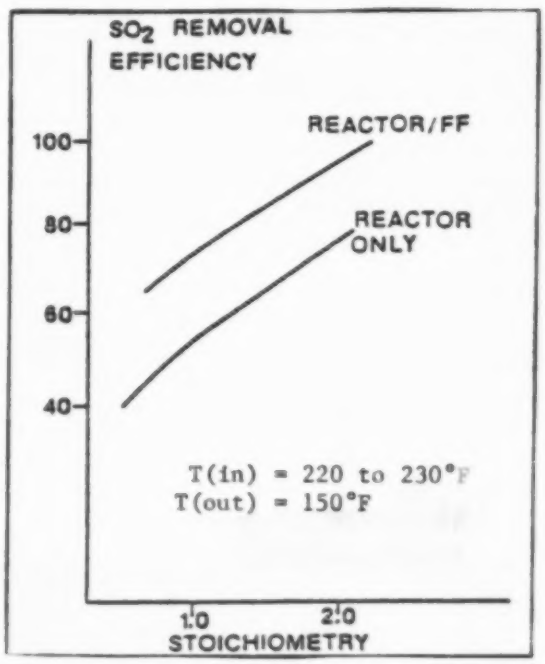


Figure 3-10. SO_2 removal performance, reactor/fabric filter (Alkali: Calcium oxide).

The particulate removal efficiency of the ESP was found to be enhanced considerably by the operation of the dry scrubber. Efficiencies of 99.3 to 99.7 percent were found with correspondingly lower current densities and higher particulate loading at the inlet to the ESP. This is attributed to the fact that the migration velocity increased due to the lower gas temperature, higher humidity, and higher sodium content of the dust.

The study of the reactor performance found that ut'lization of the alkali became lower as the stoichiometry increased. Also, the fabric filter served to significantly increase utilization in addition to increasing the SO_2 removal efficiency (Figure 3-9). This fact becomes even more important in the case of lime, which is considered a more economical alkali and can be used to obtain comparable high SO_2 removal efficiency with high utilization (Figure 3-10).

Commercial Activities

Flakt has sold a dry FGD system to a utility in Sodertalje, Sweden to treat flue gas from three coal-fired boilers (130 MWe each). This system will use an ESP as a pre-collector for fly ash which is to be used in the cement industry and therefore, has to be collected before being contaminated with the lime sorbent. The two-fluid nozzle spray dryer will be followed by a fabric filter. The system will have provisions for recycle of spent sorbent. The ash is of low alkalinity and its collection ahead of the spray dryer is expected to have a beneficial effect on the sulfur removal efficiency in terms of lime utilization. The inlet SO_2 concentration will be 900 ppm (1% S Coal). The removal guarantees are 76 percent for SO_2 and 99.8 percent for particulates. The FGD system is expected to be operational in October 1982.

Future Activities

Research work will continue in Sweden and Denmark. The focus of the research in Sweden will be on bag evaluation, while in Denmark it will be on improving performance of control and recirculation systems. At the Jim Bridger plant, effects of temperature are being tested. Beginning in February 1981, the role of fly ash in SO_2 removal will be investigated for lignite coals.

Flakt has prepared one bid for a utility system in the United States which is expected to be awarded in April 1981. Two more bids (one utility, one industrial) are being prepared and will be submitted in April.

Information Sources

Farrington, James, Flakt, Inc. Telephone Conversation with Syed Shareef, Radian Corporation. January 21, 1981.

Ahman, Stefan, et al. "Flakt's Dry FGD Technology: Capabilities and Experience." Flakt, Inc. Old Greenwich, Connecticut. October 1980.

3.12 JOY/NIRO

Address: Joy Industrial Equipment Company
Western Precipitation Division
4565 Colorado Boulevard
Los Angeles, California 90039

Niro Atomizer, Inc.
9165 Rumsey Road
Columbia, Maryland 21045

Contact for More Information: Jim Meyler
Joy/Western Precipitation Division
(213) 240-2300

Gene Steele
Niro Atomizer
(301) 997-8700

Background

Joy/Niro, after extensive pilot- and demonstration-scale test work, has been awarded contracts for six commercial utility and two industrial spray drying systems. In addition, Joy/Niro is conducting a commercial-scale demonstration program (110 MWe) at a midwestern utility.

Joy/Niro conducts fundamental research and gathers data required for bid preparation at Niro's Copenhagen research facility. Niro has also begun to investigate various disposal and utilization schemes for lime-based spray dryer wastes. Joy takes the lead in utility commercial development while Niro takes the lead in industrial commercial system work.

Research and Development

Joy/Niro relies on the 5000 acfm Copenhagen pilot facility for basic research-type test work. However, the facility is mainly used to gather site-specific data required to prepare bids for commercial systems. Coal and ash characteristics have been shown to have significant effects on SO_2 removal and sorbent utilization, but Joy/Niro has found it difficult to develop general relationships describing these effects.

Joy/Niro feels that evaluation of such site-specific factors is extremely important in preparing bids.

Niro has recently begun detailed investigation of the physical and chemical properties of the waste solids resulting from the spray drying process. These studies have generally been conducted on solids from scrubbing of flue gases generated by combustion of low sulfur lignite and western subbituminous coals. Niro has also begun evaluation of various waste disposal and utilization schemes. Last fall, Niro presented results of some of these studies at the Joint Power Conference in Phoenix. (See Information Sources below.) A summary of these results is contained in Section 4 of this report, but a few of the highlights will be discussed here.

The study found the typical spray drying process waste product to be about 75 percent fly ash, 11 percent $CaSO_3$, 6 percent $CaSO_4$, 5 percent moisture, and 3 percent $Ca(OH)_2$. The calcium sulfite and sulfate exist in the hemihydrate and the hemi- and dihydrate forms, respectively. The dried product salts are typically 50 to 100 microns in diameter, while the diameter of fly ash particles is usually between 1 and 10 microns. The bulk density of the waste solids ranges between 40 and 60 lb/ft^3. Niro claims that up to 15 percent water by weight can be added to the waste product without "seriously affecting" the handling characteristics of the solids, which are similar to conventional fly ash.

Laboratory tests were conducted to evaluate the physical properties of mixtures of the waste solids and varying percentages of water. Generally, the results indicated that such mixtures displayed properties similar to those of conventional wet FGD sludge fly ash-stabilized mixtures.

Niro has applied for a patent on a process designed to produce high strength pellets from the spray drying wastes. These pellets would be suitable for commercial use as a cement additive or as road gravel. Pilot-scale facilities, based on commercially available pelletizer designs, were used to form cylindrical pellets of various diameters. The physical properties of these pellets, specifically tensile strength and density, were reported to be similar to crushed stone. In the pelletizing process, the dry solids are mixed with water and an unspecified additive. This mixture is run through the pelletizer and the cylindrical pellets produced are stored in curing silos. Tests indicated that the pellets reached 50 percent of their final tensile strength in two days and 90 percent in 10 days. The estimated cost of producing the pellets is $5/ton of dry wastes.

Systems in Operation

Joy/Niro is currently operating a nominal 110 MWe commercial-scale demonstration facility at Northern States Power Company's Riverside Station. The system has been in operation intermittently since November

1980. Initial testing was conducted using an existing ESP for particulate collection downstream of the spray dryer. The recently completed fabric filter underwent check-out testing in mid-January 1981. Testing with the fabric filter will continue after a few weeks downtime for inspection.

Several parametric and performance tests are expected to be run with this lime-based system. Three types of coal, a 1 percent sulfur coal, a 3 percent sulfur coal, and a high sulfur coke for blending, can be fired in the Riverside boilers, thus providing a wide range of inlet SO_2 concentrations over which system performance can be evaluated. Some of the other facets of system performance that will be evaluated at Riverside are:

Variation of target removal efficiency (70 and 90 percent)

Percent solids in lime slurry feed

Temperature drop over the spray dryer

Approach to saturation at the dryer outlet

Performance of various filter bag fabrics

Comparison of ball mill and attrition slakers

Effect of solids recycle

Process control system performance

Results of the test work are expected to be presented at upcoming conferences, including the American Power Conference scheduled for April 1981 in Chicago.

Commercial Systems

Joy/Niro has been awarded a total of six utility and two industrial commercial systems. The five utility and one industrial systems that were awarded as of October 1980 are listed below. Available details on these systems were included in the Second Survey and are summarized in Table 2-1 of this report.

System	Size	Start-up Date
Basin Electric - Antelope Valley Unit 1	430 MW	April 1982
Tucson Electric - Springerville Unit 1	350 MW	Late 1984
Tucson Electric - Springerville Unit 2	350 MW	1986
Platte River - Rawhide Unit 1	250 MW	1983
Sunflower Electric - Holcombe Unit 1	350 MW	1983
Calgon - Kentucky	57,000 acfm	June 1981

Construction is in progress on the first utility system, Antelope Valley Unit 1 and on the Calgon industrial system. The Calgon system will be applied to an industrial incinerator and will use a soda ash sorbent to remove HCl and HF, as well as SO_2, from 1700°F gases. The waste liquor will be used in the associated industrial process.

The basic system design for the utility systems, all of which will treat gases from low sulfur coal-fired units, is quite similar. Joy/Niro uses a set of spray dryers (including one spare), each of which handles about 500,000 to 600,000 acfm of flue gas. Each dryer is equipped with a single rotary atomizer. Most of the system designs include solids recycle, but use of hot or warm gas bypass is included only on a site-specific basis.

The battery limits of the system design do not include waste disposal in most cases. However, at Sunflower Electric's Holcombe Station, Joy/Niro will have responsibility for disposal of the waste solids. Current plans are to add about 20 percent water by weight before landfilling the solids. Sunflower also has an option to choose the new pelletizing process described above.

Joy/Niro has sold a sixth utility system and a second industrial system since Fall 1980. Basin Electric Power awarded the joint venture a contract for its new Antelope Valley Unit 2 boiler. The boiler and spray drying system design will be virtually identical to Antelope Valley Unit 1. Construction on this spray drying system is scheduled to begin in August 1982 with initial start-up planned for early 1985. The approximate contract price of the system is $54 million. Maximum design SO_2 removal efficiency is 89 percent, but the normal operating level will be 81 percent. Antelope Valley Unit 2 will fire the same North Dakota lignite coal that will be used in Antelope Valley Unit 1. The system design will include solids recycle, but not reheat bypass.

Joy/Niro has also been awarded a contract for a spray dryer/fabric filter system to serve a coal-fired boiler at the Department of Energy's Argonne National Laboratory in Argonne, Illinois. The existing boiler, rated at 170,000 lb/steam per hour, will be converted to fire a 3.5 percent sulfur Illinois bituminous coal. The system design parameters are shown in Table 3-1. The boiler is used to provide space heat, hot water, and other building services at the Laboratory. The spray drying system, scheduled for start-up in the winter of 1981-82, will be the first full-scale commercial system to be applied to a unit firing coal with a sulfur content of more than 3 percent.

TABLE 3-1. SPRAY DRYER/FABRIC FILTER SYSTEM AT DOE'S ARGONNE NATIONAL LABORATORIES

Coal: 3.5 percent sulfur bituminous Illinois coal

SO_2 removal guarantee: 78.5 percent; 1.2 lb $SO_2/10^6$ Btu

Inlet gas temperature: 355°F

"Apparent" stochiometric ratio: 1.2 moles sorbent/mole inlet SO_2

Spray dryer diameter: 27.5 ft.

Fabric filter: 4-compartment, pulse-jet type

System includes waste recycle, but not flue gas bypass. Existing cyclones will remain in place upstream of the spray dryer. Current plans for solids disposal specify landfilling, but Argonne may investigate other disposal or utilization methods.

Source: Kelly, M.E., Radian Corporation. Personal Communication with Gene Steele, Niro Atomizer, Inc. January 13, 1981.

Future Activities

Joy/Niro is preparing two utility system bids and has one utility bid outstanding. As mentioned earlier, Joy takes the lead in bidding utility systems while Niro assumes the lead for industrial applications, but all awards are made to the joint venture.

Information Sources

Meyler, J.A., Joy/Western Precipitation Division. Telephone conversation with M.E. Kelly, Radian Corporation. January 21, 1981.

Steele, Gene, Niro Atomizer, Inc. Telephone conversation with M.E. Kelly, Radian Corporation. January 12, 1981.

Kelly, M.E., Radian Corporation. Personal communication with Gene Steele, Niro Atomizer, Inc. January 13, 1981.

3.13 KENNECOTT CORPORATION (CARBORUNDUM ENVIRONMENTAL SYSTEMS)

Address: Carborundum Environmental Systems
Kennecott Corporation
P.O. Box 87
9111 Cross Park Drive
Knoxville, Tennessee 37901

Contact for More Information: Hank Majdeski
Manager, SO_2 Project
(615) 693-7550

Mark Elizer
Process Engineer
(615) 693-7550

Background

Carborundum has conducted pilot-scale dry injection studies (1000 acfm) at their University of Tennessee facility and pilot-scale spray dryer/baghouse tests (15,000 acfm) at Basin Electric's Leland Olds Station. As an extension of the work done at Lelands Olds Station, Carborundum has been performing tests on a 1000 acfm spray dryer/baghouse system at the University of Tennessee.

Research and Development

Gas for the pilot plant at the University of Tennessee is a slipstream off an existing spreader stoker boiler with supplemental fly ash addition and spent sorbent recycle. The tests with high inlet SO_2 concentration have shown a definite correlation between SO_2 removal efficiency and the

amount of recycled sorbent. However, the amount of sorbent is limited by pumping considerations. Tests also showed that fly ash played an important role in increasing removal efficiency. In addition, a closer approach to saturation at the dryer outlet resulted in increased SO_2 removal. Current tests at the pilot facility are directed at determining SO_2 removal efficiencies of the spray dryer and the fabric filter, separately.

Commercial Activities

The foundations for the commercial dry FGD system sold to the University of Minnesota are now being prepared and construction is scheduled to begin in Spring of 1981. This system will include two spray dryers. One spray dryer will be 24.5 ft. in diameter and have a single rotary atomizer. The other dryer, 27 ft. in diameter, will have three rotary atomizers. This is expected to help comparison of performance of single and multiple atomizers and aid scaling up for future utility jobs. The Minnesota system does not have provision for solids recycle or gas bypass. The inlet temperature of the flue gas will be 375°F. The sulfur removal guarantee for the system is 70 percent at a stoichiometric ratio of 1.0, based on the inlet SO_2 concentration. The waste will be pneumatically conveyed to a silo. Plans for disposal were not available at this time.

The last bid submitted by Carborundum was for General Motors' Buick Division at Flint, Michigan. The award for this system is expected to be announced very soon. In addition, Carborundum is preparing a bid for a dry FGD system to treat flue gas from two boilers (550 MWe each) at Cajun Electric's facility in Louisiana.

Information Source

Elizer, Mark, Carborundum. Telephone conversation with Syed Shareef, Radian Corporation. January 22, 1981.

3.14 KOCH ENGINEERING

Address: Koch Engineering Co., Inc.
161 East 42nd Street
New York, New York 10017

Contact for More Information: Mike Mutsakis
(215) 682-5755

Background

Koch began development of a spray dryer-based dry FGD system in early 1979. The company is also providing assistance in operations of the Mikropul system at Strathmore Paper Company.

Research and Development

Koch Engineering has purchased a coal-fired boiler which is now being installed at their facility. The boiler will be used for test work on specific coal in order to bid commercial spray dryer systems. All future tests, like the previous tests, will be conducted on the two in-house spray dryers of 3- and 8-ft diameter. Tests on both rotary and nozzle atomizers have been performed and nozzles have been selected as the preferred choice for Koch's spray dryers.

Commercial Activities

The Strathmore system has achieved compliance performance (emission limit 0.53 lb $SO_2/10^6$ Btu) on 2 percent sulfur coal. Tests on 3 percent sulfur coal are scheduled for February 1981. Koch will release more information about their dry FGD development program and test results after the tests in February. They will also be ready to make bids for commercial applications after the high sulfur coal performance tests.

Information Sources

Mutsakis, Mike, Koch Engineering. Telephone conversation with Syed Shareef, Radian Corporation. January 7, 1981.

3.14 MIKROPUL

Address: Mikropul Corporation
10 Chatham Road
Summit, New Jersey 07901

Contact for More Information: Tom Reinauer
Vice-President of Engineering
(201) 273-6360

Background

Mikropul is a division of U.S. Filter, which includes Ducon, a wet scrubber manufacturer. Mikropul began work on a spray dryer-based FGD system in January 1978. Bayliss Industries supplied the spray dryer technology. As the result of their work, Mikropul was awarded a contract in late 1978 to provide a spray dryer/baghouse system for a coal-fired industrial boiler at Strathmore Paper Company at Woronco, Massachusetts. Bayliss Industries was later replaced by Koch Engineering for technical assistance on spray dryer design.

Commercial Activities

Mikropul's lime-based spray dryer/baghouse system at Strathmore Paper Company has now been in operation for more than a year. Strathmore's 85,000 lb steam/hr pulverized coal boiler burns about 75 tons coal/day. The sulfur content of the coal ranges from 1 to 3 percent. The system achieved compliance performance (emission limit 0.53 lb $SO_2/10^6$ Btu) on 1 to 2 percent sulfur coal conducted by a third party (Mostardi-Platt Co.) using EPA method 6. Additional tests on higher sulfur coal (about 3 percent) are scheduled for February 1981. Sulfur removal efficiency of 73 to 80 percent is being achieved on high sulfur coal at Strathmore. System operability was found to be greater than 99 percent, based on boiler availability over a 3 month period (August-October 1980). The bags at Strathmore have been in service for 14 months. They were analyzed after 12 months of service and were found to be in good condition. Mikropul feels that acrylic is the right material for fabric filters.

The Koch Engineering dryer modifications and the efforts of their technical staff have been instrumental in the imporved operations at Strathmore. Koch is continuing laboratory work toward development of new nozzles which may be available in March 1981. Mikropul's experience has shown steam atomization to require much more nozzle maintenance than air atomization. However, steam is available in the powerhouse and can be applied as a substitute for air if required. Koch is also conducting parametric tests at Strathmore. The effects of stoichiometric ratio, temperature, and other variables are being investigated. The Strathmore system has basically used high calcium lime, and both pebble and granulated lime have been evaluated. Currently pulverized lime is being used. In a few months, Mikropul intends to begin evaluation of dolomitic lime.

Adequate space was not available at Strathmore for a pneumatic waste transportation system. Waste disposal responsibilities have been contracted out to a disposal company. The Strathmore fabric filter has three dust collector modules. Adjacent to the hoppers is a container which is lifted by a special truck and taken to the disposal area (similar to dumpsters). The entire transportation system is totally covered from the collectors to the disposal area, and waste is disposed of daily.

Mikropul has made several bids for commercial systems. In addition, they have received a number of inquiries from interested parties. Inquiries have been for boilers and for a coke calciner in California. Typically, the inlet SO_2 concentration for calciners is about 1,000 ppm while the required outlet concentration in California is about 100 ppm (90 percent removal).

Information Source

Reinauer, Tom, Mikropul Corporation. Telephone conversation with Syed Shareef, Radian Corporation. January 8, 1981.

3.16 RESEARCH-COTTRELL/KOMLINE-SANDERSON AND EPA/RESEARCH-COTTRELL

Address: Research-Cottrell, Inc.
Air Pollution Control Division
P.O. Box 1500
Somerville, New Jersey 08876

U.S. Environmental Protection Agency
Industrial Environmental Research Labs
Research Triangle Park, North Carolina 27711

Contact for More Information:

Research - Dr. Nicholas J. Stevens
Manager, Chemical Process Development
Research-Cottrell
(201) 685-4887

Dr. T.G. Brna
EPA Project Officer
(919) 541-2683

Commercial - Herb Braden
Manager, Power Industry Sales and Marketing
Research-Cottrell
(201) 685-4284

Background

Research-Cottrell has completed demonstration-scale testing at two sites; privately-funded testing at Texas Utilities Big Brown Station and EPA-funded testing at Public Service of Colorado's Comanche Station. Research-Cottrell, in a joint venture with Komline-Sanderson has been awarded a contract for a commercial spray drying system to be installed at United Power Association's Stanton Station. Komline-Sanderson supplies the spray dryer equipment and technology for the joint venture systems.

Research and Development

Results of pilot testing at both Big Brown and Comanche were presented in a recent paper at EPA's FGD Symposium in Houston (See Information Sources below.) Major results of these tests are summarized below.

The test programs were conducted to identify key process parameters that affect SO_2 removal in the spray dryer/fabric filter system. Variables investigated included stoichiometric ratio, approach to adiabatic saturation temperature at the spray dryer outlet, inlet SO_2 concentration of the flue gas, and the effect of using an off-product recycle.

It was found that the stoichiometric ratio (SR) has a strong impact on SO_2 removal. Figure 3-11 shows that SO_2 removal increases sharply as SR is increased and tends to level off at higher SR values. The data shown in Figure 3-11 were reportedly obtained at spray dryer flue gas temperatures far enough removed from adiabatic saturation that this temperature effect was minimized.

The approach to adiabatic saturation temperature also has a strong influence on SO_2 removal. It was observed that a closer approach to saturation at the spray dryer outlet resulted in increased SO_2 removal. The improvement in SO_2 removal is apparently a result of increased moisture retained by the spray dried solids. Figure 3-12 indicates that the solids collected from the bottom of the spray dryer showed a significant increase in moisture content as the flue gas temperature approached adiabatic saturation. However, the moisture content of 30 to 40 percent at 20 to 30°F approaches seems unusually high in comparison with results reported for other studies.

The concentration of SO_2 in the inlet flue gas appears to have only a moderate effect on SO_2 removal over the range investigated. Figure 3-13 shows that SO_2 removal in the spray dryer decreases gradually with increasing flue gas inlet SO_2 concentrations between 400 and 2000 ppm SO_2. SO_2 removal in the fabric filter has a similar dependence on the inlet SO_2 concentration.

The effect of recycling a portion of the spray dryer off-product was also analyzed. By recycling a mixture of the spray dryer off-product and fly ash solids SO_2 removal was significantly enhanced. Figure 3-14 illustrates that SO_2 removal can be improved from 53 percent without recycle to a maximum of 62 percent with recycle at a SR of 1.0. SO_2 removal in the spray dryer increases with increasing recycle ratio, but begins to level off at 2.5 to 3.0 lb recycle solids/lb makeup lime.

SO_2 removal in the fabric filter was also analyzed. It was found that SO_2 removal in the fabric filter followed the same trends as removal in the spray dryer. Both the stoichiometric ratio and the approach to adiabatic saturation temperature at the spray dryer outlet had a strong impact upon SO_2 removal. However, an analysis of the air-to-cloth ratio showed that variation from 1.3 to 2.5 ft/min had little impact upon SO_2 removal.

The characteristics of the dry wastes from the Comanche tests have been evaluated in preliminary laboratory tests. The Comanche fly ash is highly cementitious and has a high reactive CaO content. Results of the preliminary tests indicate that the dry wastes (from tests with lime) are similar to wet FGD sludge/fly ash mixtures. Initial permeabilities of the lab samples were in the 10^{-5} cm/sec range, but after 28 days of curing at ambient conditions, the permeability dropped to the 10^{-7} cm/sec range. (10^{-6} cm/sec is equal to approximately 1 ft/year.)

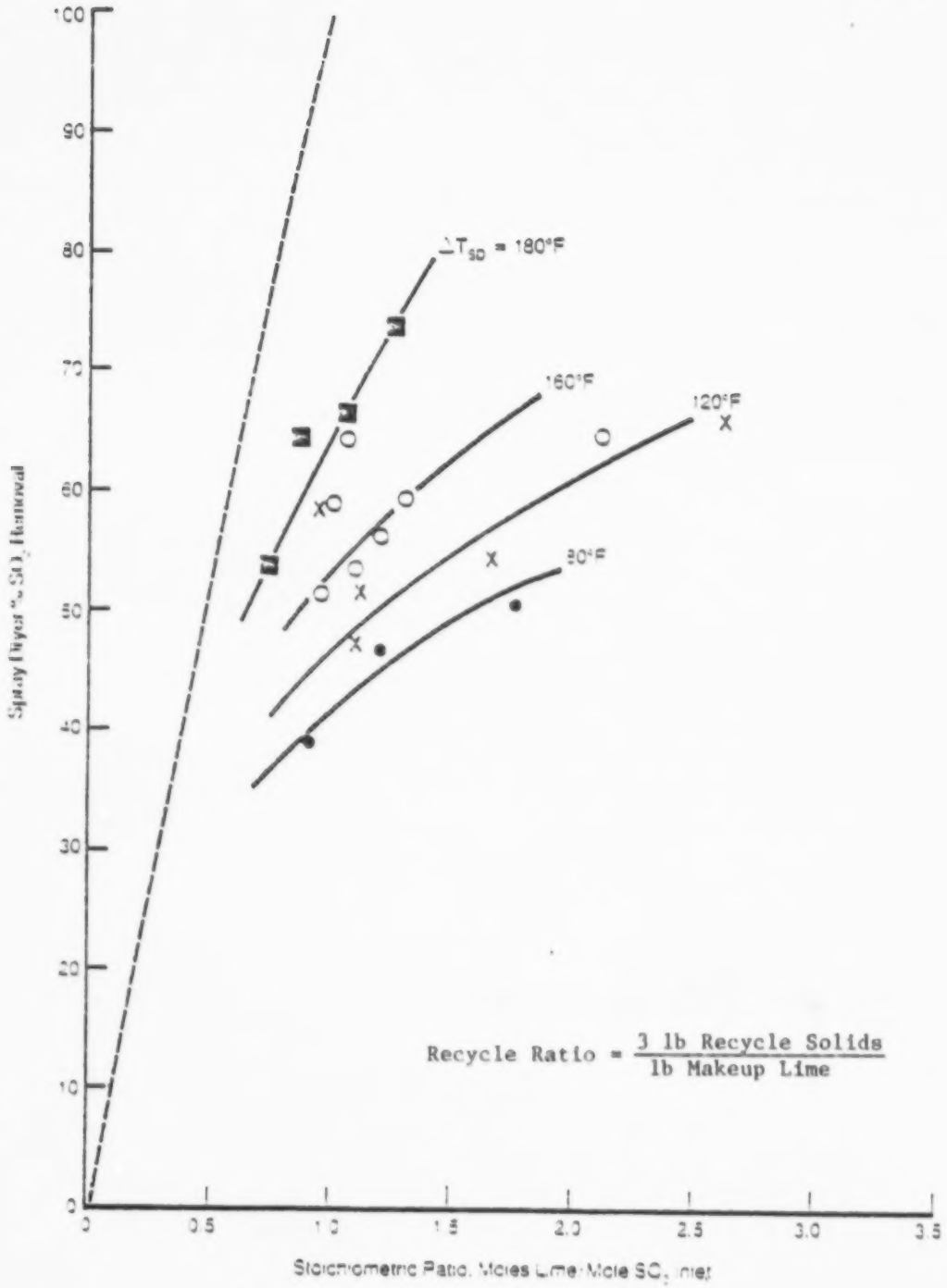


Figure 3-11. Effect of Stoichiometry on Spray Dryer SO_2 Removal.

Source: Stevens, Nicholas J. (See Information Sources at the end of this section.)

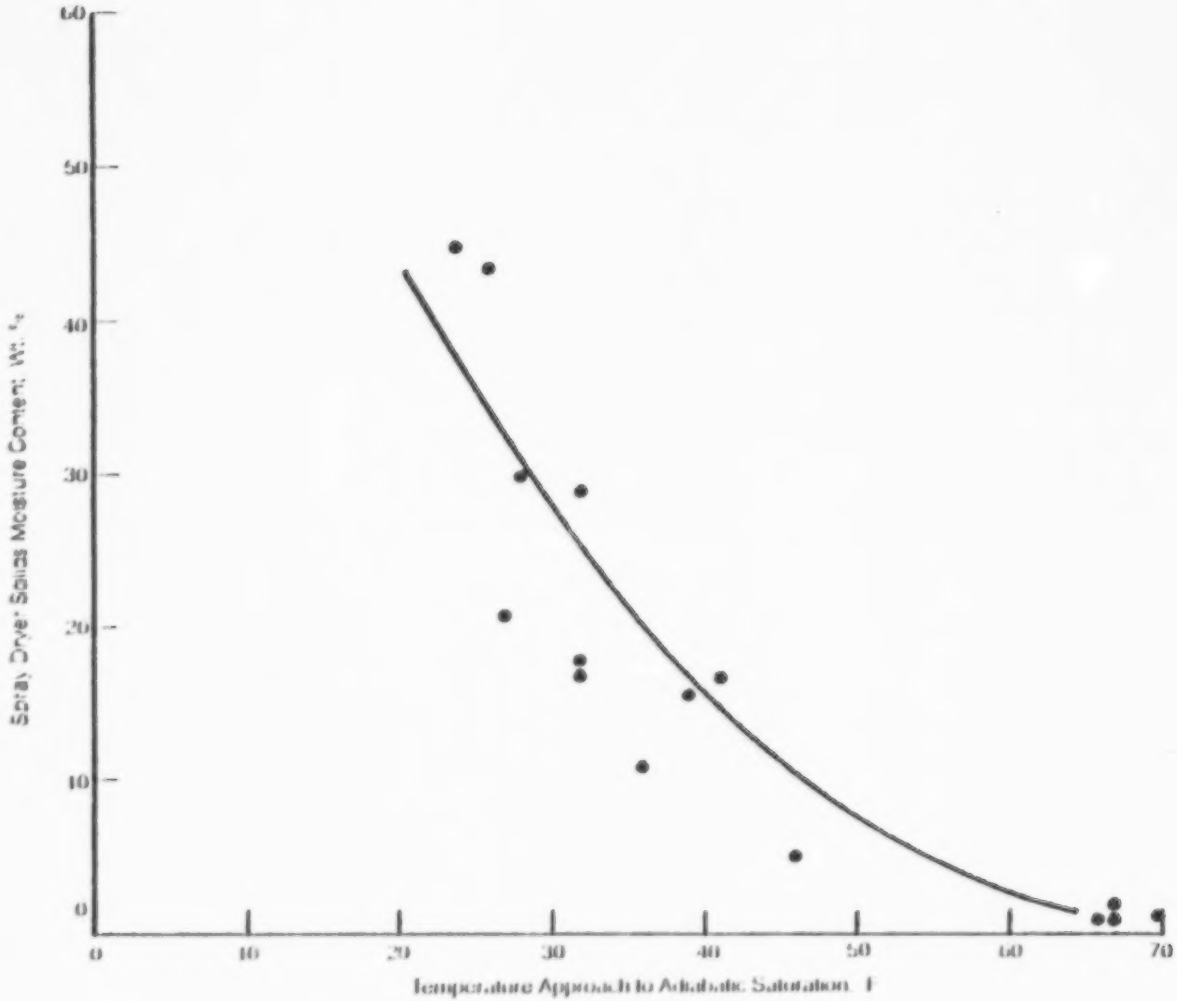


Figure 3-12. Effect of Flue Gas Temperature Approach to Adiabatic Saturation on Spray Dryer Solids Moisture Content.

Source: Stevens, Nicholas J. (See Information Sources at the end of this section.)

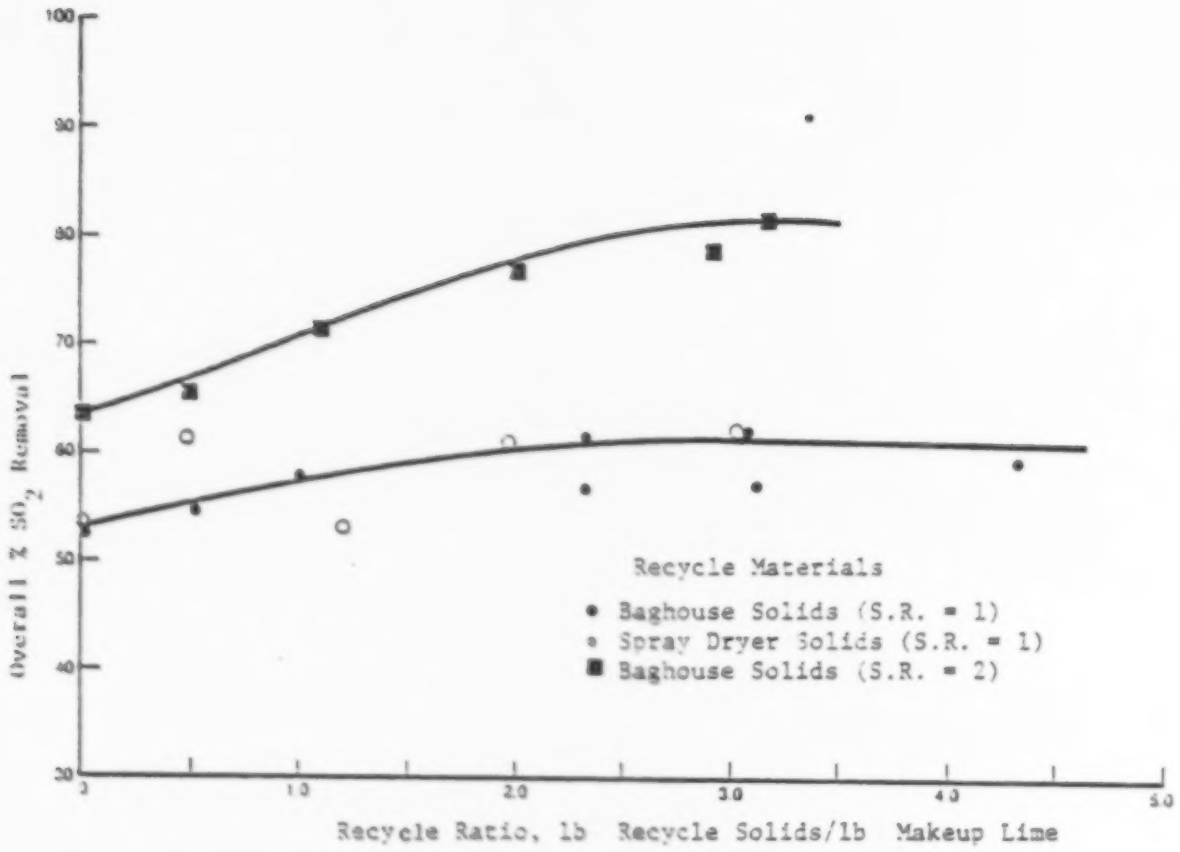


Figure 3-13. Effect of recycle ratio on overall SO_2 removal.

Source: Stevens, Nicholas J. (See Information Sources at the end of this section.)

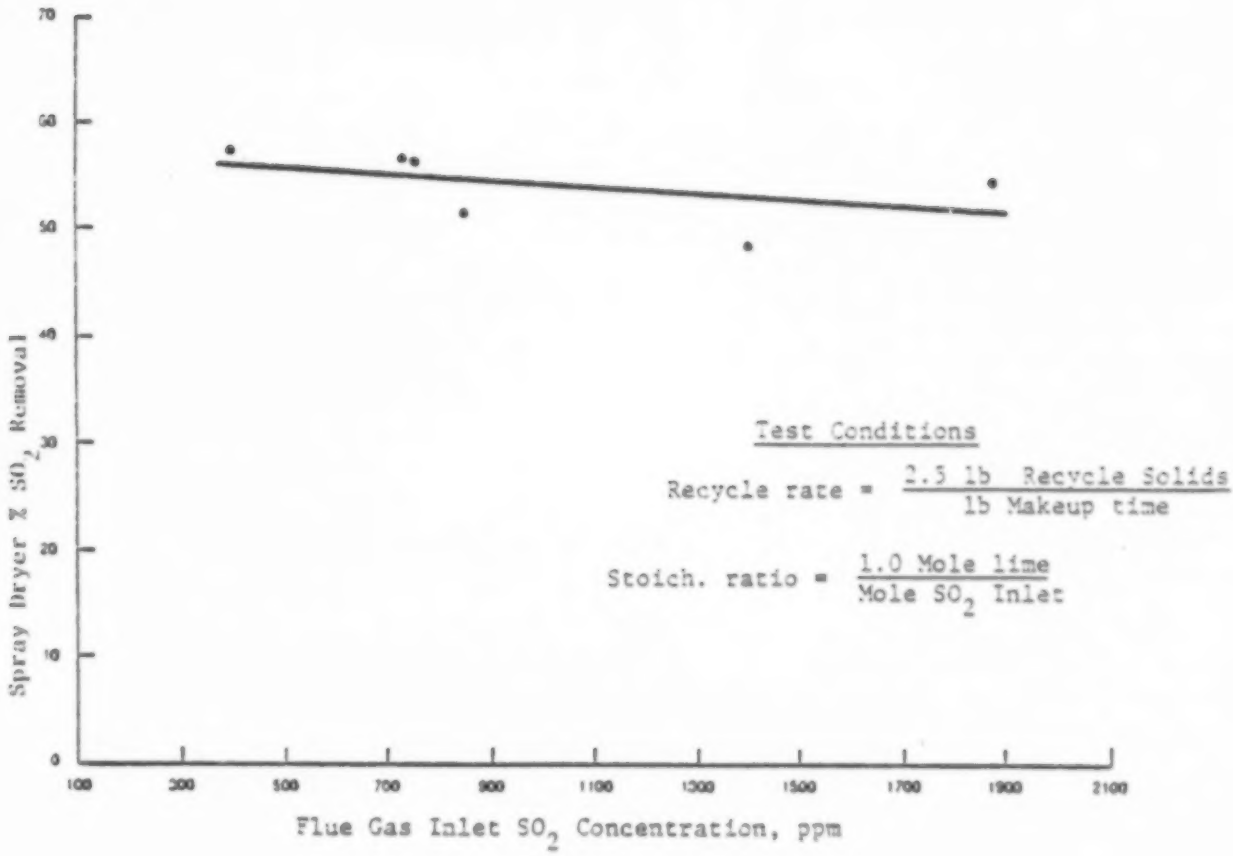


Figure 3-14. Effect of inlet SO_2 concentration on spray dryer SO_2 removal.

Source: Stevens, Nicholas J. (See Information Source at the end of this section.)

Although EPA-funded test work at Comanche has been completed, Research-Cottrell plans to use the system to gather site specific data required for bid preparation. A final report on the test work, including a "techno-economic" evaluation of the spray dryer fabric filter system, will be submitted to EPA in Spring 1981.

Commercial Activities

Construction of the spray dryer-based system for the United Power Association's Stanton Station 64 MWe coal-fired boiler is slated to begin in April 1981. November 1982 is the target date for commercial operation. The lime-based system will consist of a single 38-ft. diameter carbon steel spray dryer, equipped with three 60-hp rotary atomizers, followed by a 10-compartment reverse air fabric filter. The boiler at Stanton will fire a North Dakota lignite with average sulfur content of 0.77 percent. The SO_2 removal guarantee is 72 percent when the 0.77 percent sulfur coal is fired. The spray dryer system design does not include solids recycle, but there will be provisions for flue gas bypass. Table 3-2 summarizes the design and operating parameters for the Stanton Station system. The estimated turnkey cost of the system is five million dollars.

Current plans for disposal of the dry wastes stipulate landfilling. There is natural clay in the plant area and annual rainfall is low. Both of these factors contribute to the viability of the landfill process as a means for disposal of the dry wastes.

Future Activities

Research-Cottrell has not sold any new systems since Fall 1980, but they are continuing to market to both industrial and utility clients.

Information Sources

Stevens, Nicholas J., Research-Cottrell. Telephone conversation with M.E. Kelly, Radian Corporation. January 5, 1981.

Braden, Herbert, Research-Cottrell. Telephone conversation with M.E. Kelly, Radian Corporation. January 5, 1981.

Research-Cottrell; Air Pollution Control Division. Technical Bulletin: Spray Dryer-Fabric Filter Contract. Research-Cottrell. Somerville, New Jersey. 1980.

Stevens, Nicholas J. Dry SO_2 Scrubbing Pilot Test Results. (Presented at EPA's Sixth FGD Symposium, Houston, Texas. October 28-31, 1980.) Research-Cottrell. Somerville, New Jersey.

TABLE 3-2. DESIGN AND OPERATING PARAMETERS FOR SPRAY-DRYER/FABRIC FILTER SYSTEM AT STANTON STATION, UNITED POWER ASSOCIATION[a]

Equipment Specifications:

38-ft. diameter carbon steel spray dryer equipped with 3 centrifugal (rotary) atomizers (each at 14,000 rpm, 60-hp motors)

10-compartment reverse-air-cleaned fabric filter with 300 fiberglass bags per compartment. Bags have an acid-resistant polymer coating and a Teflon/silicon graphite finish.

Operating Parameters:

Coal-North Dakota lignite

Property	Typical	Range
Moisture	35.6%	28.0 - 37.9%
Ash	6.9%	4.9 - 11.8%
Volatile matter	26.4%	25.1 - 32.0%
Fixed carbon	31.1%	29.4 - 34.4%
Sulfur	0.77%	0.33 - 1.94%

Flue gas flow: 324,500 acfm maximum at 323°F

Inlet gas temperature: 268 to 323°F (268°F at 50% load)

Fabric filter net air-to-cloth ratio: 2.23:1

Typical stochiometric requirements[b]: 1.25 lb mole lime/lb mole SO_2 inlet

Particulate emission guarantee: 0.03 lb/10^6 Btu

SO_2 removal guarantee: 0.6 lb/10^6 Btu or 70% SO_2 removal (whichever results in lower SO_2 emissions)

[a]Source: Research-Cottrell; Air Pollution Control Division. Technical Bulletin: Spray Dryer - Fabric Filter Contract. Research-Cottrell. Somerville, New Jersey. 1980.

[b]For 0.77% sulfur lignite; not a system guarantee; without recycle and assuming 85% lime purity.

3.17 ROCKWELL INTERNATIONAL

Address: Environmental & Energy Systems Division
Rockwell International
Energy Systems Group
8000 DeSoto Avenue
Canoga Park, California 91304

Contact for More Information: Dr. Dennis G. Gehri, Project Manager
ACP Research, Development and Applications
Rockwell International
(213) 341-1000 ext. 2513

Background

The former Rockwell International/Wheelabrator-Frye venture sold two commercial systems: a utility system to Otter Tail Power Company (Coyote Station) for a 410 MWe utility boiler and an industrial system (65,000 acfm) to Celanese Fibers Company. Both are spray dryer/baghouse systems.

Since the dissolution of the joint venture in January, both Rockwell and Wheelabrator-Frye have continued to be involved in dry FGD projects. For future commercial sales, Rockwell will bid the entire system and subcontract the particulate collection portion of the process.

Research and Development

Rockwell's primary R&D site has been a 5000-acfm pilot spray dryer installed at Commonwealth Edison's Joliet Station. The system includes reverse-air and pulse-jet fabric filters and an ESP for particulate collection. Initial start-up and checkout testing began in July 1979. The Joliet Station has been used primarily for preparing bids and conducting pilot-scale research toward refinement of the dry FGD technology. Recent tests at Joliet have been conducted at inlet SO_2 concentrations of up to 2,000 ppm.

The mobile unit used by Rockwell in testing at various locations last year (including PP&L's Jim Bridger plant) has been reassembled at their Canoga Park facility. The unit may be moved to an eastern utility site in the near future.

Rockwell's waste disposal studies have shown dry FGD waste to have no hazardous properties. The fly ash and calcium-based product salts mixture (dry density = 100 lb/ft^3) has been found to be suitable for landfill disposal with appropriate protection. Three phases of waste disposal have been studied by Rockwell:

1) Equipment required for transferring wastes from collector to storage silo.

2) Transportation from silo to disposal area.

3) Equipment required to lay down waste at landfill site.

The dry waste has been found to be very amenable to pneumatic transportation from the collector to the silo. Some moisture addition is usually necessary to prevent dusting during transportation from the silo to the disposal area. No special equipment is required at the disposal site.

Commercial Activities

The Celanese system has been operating for the past few months without any major problems. The Coyote plant is in start-up now and the facility is scheduled to begin operation soon. Rockwell has not made any commercial sales recently, but they have submitted two proposals (one industrial, one utility) that are under evaluation. Two more utility bids are being prepared for submission by the Spring of 1981.

Information Source

Gehri, Dennis, Rockwell International. Telephone Conversation with Syed Shareef, Radian Corporation January 7, 1981.

3.18 STORK-BOWEN ENGINEERING, INC.

Address: Stork-Bowen Engineering, Inc.
P.O. Box 898
Somerville, New Jersey 08876

Contact for More Information: Edward Biedell
Senior Process Engineer
Air Pollution Control Systems
(201) 725-3232

Background

A gas cleaning process originated by Leisegang Umwelttechnik KG, Berlin, reportedly incorporates the higher removal efficiency advantage of a wet scrubber with dry waste product capability of a spray dryer. Patents on the scrubber design have been issued by the U.S., South Africa, and Spain, and are expected from several other countries. Stork-Bowen is the exclusive licensee for this process in the U.S., Canada, and Mexico.

The Stork-Bowen/Leisegang (SB/L) process is particularly geared toward small and medium-scale industrial gas cleaning applications. High removal efficiencies are reported using conventional reagents, such as lime, for SO_2 removal. Solids formed by reaction and particulates in

the entering gas stream are collected in the scrubber slurry and then returned to the spray dryer to be discharged as a neutral dry powder. In addition to particulates, the SB/L process can control contaminants such as SO_2, SO_3, HCl, HF, and other acid gases from chemical plants, smelters and other minerals operations, foundries, and waste incinerators. The first commercial installation of the SB/L process went on-stream in mid-1979 on a cupola exhaust at a large foundry in West Germany. The system has since been operating without any major problems and is reported to meet all emissions standards.

Commercial Activities

In addition to the SB/L process, Stork-Bowen also designs and builds spray dryers. In November 1980, Stearns-Roger awarded a contract to Stork-Bowen to provide a spray dryer and recycle equipment to be used for an EPRI-sponsored pilot project at Arapahoe Station of Public Service Company of Colorado. The system will be equipped to handle 2,000 to 6,000 scfm. Lime, limestone, and soda ash are the sorbents to be tested with SO_2 concentrations up to 2,000 ppm.

The project will be overseen by Stearns-Roger on behalf of EPRI. Stearns-Roger is now pouring foundations for this relocatable test facility. The equipment is expected to be delivered in Spring of 1981 and construction is scheduled to be complete by summer.

Information Source

Biedell, Edward, Stork-Bowen. Telephone conversation with Syed Shareef, Radian Corporation. January 7, 1981.

3.19 WHEELABRATOR-FRYE, INC.

Address: Wheelabrator-Frye, Inc.
Air Pollution Control Division
600 Grant Street
Pittsburgh, Pennsylvania 15219

Contact for More Information: Peter Maurin
(412)288-7300

Background

The Wheelabrator-Frye/Rockwell International venture has sold two commercial systems: to Otter Tail Power Company (Coyote Station) for a 410 MWe utility boiler and to an industrial system (65,000 acfm) to Celanese Fibers Company. Both are spray dryer/baghouse systems. (See pages 87-88 for the discussion of these systems).

Wheelabrator-Frye and Rockwell dissolved their joint venture in January 1980. Both companies are continuing to be involved in systems sold by their joint venture. In addition, Wheelabrator-Frye is continuing active involvement with dry FGD work, drawing on experience of their divisions and subsidiaries in design, fabrication, and installation of spray dryer/baghouse systems.

Research and Development

Work is continuing at Commonwealth Edison's Joliet Station on optimization of rotary atomizers. The Joliet pilot facility is alternately used for three months each by Wheelabrator-Frye and Rockwell for developmental work. Wheelabrator-Frye's other pilot facility is at Swenson Division of Whiting Corporation at Harvey, Illinois. At this facility, a gas-fired dryer is used for conducting tests on the 3,000 to 5,000 acfm scale. The Swenson Division facility has provisions for SO_2 and fly-ash spiking. Developmental work at Swenson includes optimization of air-atomized nozzles and the study of dryer geometries and gas-liquid mixing. Wheelabrator-Frye also has an R&D facility at Mishawaka, Indiana where current work is directed at flow modeling activities for ESP's, fabric filters, and spray dryers.

Wheelabrator-Frye's involvement with dry injection work during the early 70's has indicated the technology to be suitable for low sulfur applications for industrial and process operations. The company feels that it has a good understanding of dry injection technology and is currently doing only supplementary work in this area.

Commercial Activities

Almost two dozen budget proposals submitted by Wheelabrator-Frye led to about half-a-dozen formal proposals for spray dryer FGD systems. Announcements of awards of some of these proposals are expected in the Spring of 1981.

Information Source

Maurin, Peter, Wheelabrator-Frye. Telephone Conversation with Syed Shareef, Radian Corporation, January 29, 1981.

SECTION 4

DRY FGD WASTE DISPOSAL

The collective experience of the U.S. utilities and industries in operating wet scrubbers and disposing of scrubber waste (sludge, fly ash) has been studied and documented fairly extensively. Studies have been aimed at (1) developing a data base on sludge and ash handling procedures, (2) providing independent evaluations of the sludge fixation processes, (3) quantifying variables affecting the solubility of trace elements and potentially toxic species from solid waste by-products, and (4) establishing guidelines for the construction of sludge disposal facilities.

Similar efforts directed at characterization, disposal, and utilization of waste from dry SO_2 control systems are only now getting underway. As more commercial dry FGD systems begin to operate, these efforts can be expected to gain momentum, and a broader data base should begin to emerge. This section presents some of the findings of the research work in the area of dry FGD waste characterization. In addition, the scope of on-going studies on waste characterization and the current and planned disposal methods for commercial sized dry FGD systems sold to date are also presented.

4.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

Under the Resource Conservation and Recovery Act (RCRA), solid waste is defined as "any garbage, refuse, sludge from a waste water treatment plant, water supply treatment plant, or air pollution control facility . . . . " The RCRA further defines a hazardous waste as any solid waste not excluded under Section 261.4 of RCRA. These exclusions are domestic sewage, suspended or dissolved solids in industrial waste waters, household wastes, agricultural wastes, mining wastes, fly ash, bottom ash, slag, FGD waste from coal burning sources, and drilling mud. If not specifically excluded, then hazardous wastes are either listed in Subpart D, contain chemicals listed in Subpart D, or exhibit any hazardous characteristics. Dry FGD waste is not listed in Subpart D and does not contain chemicals listed in Subpart D. (The hazardous characteristics mentioned under the law are ignitability, corrosibility, reactivity, and toxicity). Summarized below are the results of some of the studies conducted to characterize dry FGD waste.

(a) Chemico, a division of Envirotech Corporation, has conducted EPA-sponsored studies to determine various physical and chemical properties of the dry FGD waste solids mixed with varying amounts of water. A mixture of 80 percent solids and 20 percent water displayed the most desirable properties in terms of disposal requirements. The unconfined compressive strength of the mixture was found to be about 12,000 lb/ft^2,

and the permeability was less than 10^{-5} cm/sec. These values are similar to those for conventional fly ash stabilized FGD sludges. The leachability of heavy metallic compounds, as determined in the laboratory tests, was found to be well within the limits set by EPA as guidelines for definition of a hazardous waste.

(b) Battelle-Columbus Laboratories, under a contract to the Buell Emission Control Division, has conducted a technical and economic feasibility study (sponsored by the EPA) of the Sinterna* process for disposal of dry FGD wastes. Laboratory-scale studies were conducted on the powdered solid waste that was generated during nahcolite dry injection tests conducted by Buell at Colorado Springs' Martin Drake Station.

Sodium-based wastes present a disposal problem because of their high leaching potential. Untreated sodium-based dry FGD wastes are not considered suitable for disposal by conventional landfill methods. The Sinterna process is designed to produce stabilized pellets from the untreated wastes by insolubilizing sodium salts through lime addition and curing at ~950°C. These pellets are considered suitable for landfill disposal because of reduced leaching potential.

The Sinterna process involves three steps: (1) pelletization, (2) drying, and (3) sintering. Spherical pellets (about 3/8" in diameter) are formed from the untreated dry wastes in a disc pelletizer, after addition of 5 percent hydrated lime as a binder. The pellets are dried and then fired in a sintering grate-type furnace at 925 to 1000°C. The sintering creates a "glassy" phase, and the final pellets are quite strong. A certain percentage of the sulfur in the pellets is converted to SO_2 during sintering, depending on the firing temperature. This waste gas must be treated in the FGD system if it cannot be vented to the atmosphere.

The laboratory tests showed that the sulfate leaching could be reduced from the 60 percent typical of a dried, unsintered pellet to about 20 percent after sintering. The amount of leaching is measured by placing the pellets in a continuously stirred beaker of water and sampling the water at set intervals, with the analysis at 100 hours being used as the standard for comparing sintered and unsintered pellets. Using this method, it was observed that pellets (dried at 105°C) showed 60 percent sulfate leachability after 100 hours, while the comparable figure for pellets sintered at 1000°C was about 20 percent, and about 30 percent of the sulfur was converted to SO_2. Reducing the sintering temperature to 925°C reduced the conversion of sulfur to SO_2 to about 10 percent, while 65 percent of the sulfur was found to have leached out of the pellet (at 100 hours). A sintering temperature of 1000°C was found to provide the best balance between reduced sulfate leaching and conversion of sulfur to SO_2.

Although the Sinterna process appears to be technically feasible, and the sintered pellets have properties more suitable for landfill than untreated waste or dried pellets, it does not appear to be economically

*Patented process held by Industrial Resources, Inc.

feasible. The estimated annualized cost (including capital charges for pelletizing, drying, and sintering equipment) is $100/ton of dry waste. The capital cost of the process for a conceptual 500 MWe plant (producing about 20 tons/hour of nahcolite-based dry injection wastes) was estimated to be about $20 million.

(c) In an EPA-sponsored study, Cottrell Environmental Sciences, Inc. has evaluated the characteristics of the spray dryer waste generated at Public Service Company of Colorado's Comanche Station. The Comanche fly ash is highly cementitious and has a high reactive CaO content. Results of the preliminary tests indicate that the dry wastes (from tests with lime) are similar to wet FGD sludge/fly ash mixtures. Initial permeabilities of the lab samples were in the 10^{-5} cm/sec range, but after 28 days of curing at ambient conditions, the permeability dropped to the 10^{-7} cm/sec range.

(d) Niro Atomizer, Inc. has also conducted research on disposal of wastes from dry FGD systems. The properties of dry wastes have been investigated and alternatives for disposal, depending on the properties of the specific waste material have been developed. The composition of the wastes was found to vary with coal composition and process conditions in the scrubber. For low sulfur western coals, the fly ash dominates the waste material and its characteristics are, therefore, very important. A typical spray drying waste product analysis for a low sulfur coal unit is as follows:

Fly ash	75%
$CaSO_4$	6%
$CaSO_3$	11%
$Ca(OH)_2$	3%
H_2O	5%

Due to the small amount of oxygen in the flue gas from modern boilers, only a small amount of calcium sulfite is oxidized to sulfate in the spray dryers. When dry, the powder is fairly stable and oxidizes very slowly on exposure to air. The calcium sulfite exists as the hemihydrate and the sulfate as the hemi- and dihydrate. A portion of the calcium sulfate is co-precipitated as a solid solution with the calcium sulfite. All these compounds exhibit relatively low solubilities.

The excess reagent in the powder is present as hydrated lime. When freshly produced the powder contains approximately 5 percent moisture. This is tied up by hydration reactions in a few hours. The spray dried reaction products are spheres of 50 to 100 microns diameter. The fly ash is typically 1 to 10 microns and may be spheres or irregular shapes. Because the fly ash dominates the mass of material, it also dominates the physical properties. Bulk densities are typically 40 to 60 lb/ft^3. The material is easily fluidized and moved by conventional ash handling equipment. For coals with high sulfur and low ash, the fly ash fraction of the waste may decrease to slightly below half. This has only minor impacts on physical properties. The primary change is an increase in density but the material remains easy to handle.

Fly ash from western coals has pozzolanic properties. A pozzolan is a material containing silicon or aluminum and silicon compounds. Alone it has no hardening qualities, but exposed to water at normal temperatures it reacts with calcium hydroxide to a cementlike material.

The critical parameters for a landfill material are density, compressive strength, permeability, and the composition of the leachate and run-off generated. Table 4-1 shows typical data from Niro's lab tests with dry FGD waste product. Niro claims that 80 to 90 percent of the lab measured dry density and compressive strength can be obtained in a landfill. High density is desirable in that it permits more material to be disposed of in a given amount of land. Compressive strength is important in that the landfill must support its own weight, sometimes in a thickness of 50 to 100 ft and should allow trucks and earth moving equipment to move on its surface without getting stuck. Low permeability reduces the risk that rain water will leach through the landfill and contaminate the groundwater underneath with soluble salts.

Niro has found that the addition of sufficient water to lubricate the grains of dry material will allow a greater final density for the same amount of compactive effort. Once the material is wetted and compacted into the landfill it undergoes several chemical reactions that bind the individual particles together and fill the remaining void space with impermeable reaction products. The first reactions to take place are hydrations. The fly ash contains considerable calcium oxide which combines rapidly (in a few minutes) with water to form calcium hydroxide. Calcium sulfate hemihydrate combines with water somewhat more slowly to form the dihydrate. Much slower reactions form calcium-silicon-aluminates and sulfo-aluminates over a period of days and months. Much of the ultimate strength of the cured product comes from these compounds.

The compressive strength of the landfilled material, as reported by Niro, is normally 100 to 150 psi, permeability is 10^{-6} cm/sec or less and density is 100 lb/ft^3. (A permeability of 10^{-6} cm/sec equals 1 ft/year and a density of 100 lb/ft^3 is a normal value for compacted soil.)

Niro concludes that the outcome of landfill disposal is a block of solidified waste 50 to 100 ft. deep. It is essentially inert and impermeable, may be covered with soil and revegetated, is strong enough to support light construction and may be excavated or drilled like soft rock or hard soil.

An alternative method of dry FGD waste disposal that may have less impact on the environment and could result in lower disposal costs has also been developed by Niro, Inc. If the powder is exposed to a higher degree of compression at lower water content, it is possible to form pellets.

TABLE 4-1. STRENGTH AND PERMEABILITY VARIATION WITH DIFFERENT ASH TYPES

Coal Type	Lignite (USA)		Subbit. (USA)		Lignite (USA)	
Parameter						
% H_2O added	20	40	32	45	45	60
Dry Density lb/ft^3	91	76	90	69	73	62
Compressive Strength, psi						
7 days @ 73°F	47	803	-	-	-	-
28 days @ 73°F	93	984	400	3000	100	600
7 days @ 100°F	-	1824	-	-	-	-
28 days @ 100°F	-	1346	-	-	-	-
Permeability, cm/sec						
7 days @ 100°F	$2.0x10^{-6}$	$2.2x10^{-6}$	-	-	-	-
14 days @ 100°F	$6.2x10^{-7}$	$2.1x10^{-6}$	-	-	-	-
28 days @ 100°F	-	$1.9x10^{-6}$	-	-	-	-
28 days @ 73°F	-	-	-	-	$2x10^{-7}$	$2x10^{-7}$
3 months @ 73°F	-	-	-	$9x10^{-10}$	$2x10^{-7}$	-

- not measured

Source: Buschman, J.C. et al. "Disposal of Wastes from Dry SO_2 Removal Processes", Niro Atomizer, Inc. Presented at Joint Power Generating Conference, Phoenix, Arizona, 1980.

of high strength suitable for commercial uses. The "synthetic gravel" is produced by adding 10 to 20 percent water to dry FGD waste and compressing it to between 2.5 and 3.0 times its loose density. This is reported to result in a cured density of about 120 lb/ft^3 and a compressive strength of over 10,000 psi.

Niro has investigated the production of gravel with different dry FGD products. Due to the different fly ash composition for each coal, a different set of gravel properties results for each waste product. The chemical composition of the fly ashes used to produce gravel by Niro are presented in Table 4-2. Table 4-3 shows the properties of pellets produced from three different waste products. The optimum moisture to be added varies as does the maximum dry strength and splitting strength. Niro has cylindrical pellets in 3/16 in., 1/4 in., 3/8 in., and 1/2 in. sizes. The pellets are reported to be equivalent in all respects to commercial crushed stone. Physical properties of these pellets are shown in Table 4-4. The results indicate that the larger pellets exhibit lower tensile strengths. However, Niro claims that pellets with good performance properties can be made over a wide range of sizes.

The gravel reaches 50 percent of its strength in 2 days and 90 percent in 10 days. The pellets are reportedly not affected by water, ordinary heat, freeze, thaw, or mechanical handling. Cold weather as well as excessive dryness does slow down the curing process. However, the return of heat or moisture is reported to permit curing to continue. Therefore, Niro claims that the gravel may be silo cured a few days before use or may be stock-piled outdoors for years.

Niro has estimated the capital cost for a dry FGD waste disposal system to be about $9/kW and the operating cost to be about 0.8 mills/kWh. These estimates compare favorably with TVA's estimate for wet FGD (lime/limestone) waste disposal costs of about $17kW for capital cost and 1.08 mills/kWh. for operating cost. According to Niro, the difference in the costs are primarily due to the elimination of the thickening and filtration modules for a dry system. The breakdown of the capital and operating costs for both the wet and dry system are shown in Table 4-5.

(e) Other companies that are currently engaged in work on dry FGD wastes include Rockwell International and IU Conversion Systems. Details of the results of their work are not available at this time.

4.2 SCOPE OF ONGOING STUDIES ON DRY FGD WASTE CHARACTERIZATION

In addition to the EPA-supported work by Cottrell Environmental Sciences at Comanche Station, two major studies are currently underway aimed at characterizing the physical and chemical characteristics of dry FGD wastes. The scope of these studies is briefly described below:

TABLE 4-2. CHEMICAL ANALYSIS OF FLY ASH COMPRISED IN FGD GRAVEL (Wt%)

Fly Ash Component	Coal Sample 1	2	3
SiO_2	28.6	33.7	51.9
Al_2O_3	12.4	23.0	26.7
Fe_2O_3	8.5	4.2	4.1
CaO	25.8	28.7	11.5
MgO	7.4	6.0	1.1
Na_2O	5.2	2.7	1.3
K_2O	0.7	0.4	0.9
TiO_2	1.0	0.5	-
P_2O_5	0.6	-	0.2
SO_3	5.8	2.5	-
LOI	0.8	0.8	1.2

Source: Buschman, J.C. et al. "Disposal of Wastes from Dry SO_2 Removal Processes". Niro Atomizer, Inc. Presented at Joint Power Generating Conference. Phoenix, Arizona. 1980.

TABLE 4-3. PROPERTIES OF PELLETIZED DRY SCRUBBER PRODUCTS

Days of curing at 100°F		Coal Sample						
		Coal 1			Coal 2		Coal 3	
		g H_2O added/100 g solids						
		10	15	20	15	20	20	25
10	Dry density, lb/ft^3	129	111	94	127	109	99	68
30		132	110	84	126	107	99	87
60		131	109	88	126	107	99	89
10	Splitting	460	170	3	750	430	270	140
30	strength, lb/in^2	729	329	0	1099	574	492	180
60		732	367	0	1060	544	500	173

Source: Buechman, J.C. et al. "Disposal of Wastes from dry SO_2 removal processes". Niro Atomizer, Inc. Presented at Joint Power Generating Conference, Phoenix, Arizona, 1980.

TABLE 4-4. PROPERTIES OF DIFFERENT SIZE PELLETS PRODUCED FROM DRY SCRUBBER WASTE

Curing Time / Curing Temp.		2 days ambient			10 days 100°F			10 Days 140°F		
ADDITION OF H_2O (g H_2O/100 g solids)		20	17.5	15	20	17.5	15	20	17.5	15
PELLET SIZE										
3/16"	Dry pellet density, lb/ft^3	-	116	-	-	122	-	-	122	-
1/4"			110	115	124	-	116	127	116	121	127
3/8"		-	115	121	-	117	123	-	118	125	
1/2"		-	118	121	-	120	122	-	120	125	
3/16"	Splitting tensile strength, lb/in^2	-	462	-	-	1000	-	-	1360	-
1/4"		334	409	736	796	794	995	806	1100	1200	
3/8"		-	288	405	-	544	676	-	603	700	
1/2"		-	435	532	-	537	708	-	602	754	

Source: Buschman, J.C. et al. "Disposal of Wastes from dry SO_2 removal processes". Niro Atomizer, Inc. Presented at Joint Power Generating Conference. Phoenix, Arizona. 1980.

TABLE 4-5. CAPITAL AND OPERATING COSTS OF DISPOSAL OF WET FGD SLUDGE AND DRY FGD WASTE

Module	Fly Ash Handling	Thickening	Filtration	Mixing	Disposal	Total
		WET FGD (lime/limestone)				
Capital $/kW	4.5	6.5	2.5	0.9	2.8	17.2
Operating mills/kWh	0.22	0.25	.11	0.05	0.45	1.08
		DRY FGD				
Capital $/kW	5.3	0	0	0.9	2.8	9.0
Operating mills/kWh	0.28	0	0	0.05	0.45	0.78

Source: Buschman, J.C. et al. "Disposal of Wastes from dry SO_2 removal processes". Niro Atomizer, Inc. Presented at Joint Power Generating Conference. Phoenix, Arizona. 1980.

(a) EPRI has recently begun a study to characterize the physical and chemical properties of solid waste from spray drying and dry injection systems. A total of 30 solid samples will be used to identify those parameters which impact the handling and disposal of dry FGD wastes. The parameters will also provide comparative data concerning the effects of system design and coal type on the physical and chemical make-up of the solids. The techniques to be used for the analysis will include the following:

(i) Morphology: Scanning electron microscope (SEM) techniques are used to characterize dry FGD products, precipitator ash, and wet FGD sludge. Electron micrographs are useful for comparing gross physical factors such as morphology and general particle size distribution. These factors influence the settling properties, packing density, and permeability of the solid waste.

(ii) Elemental Analysis: The elements to be analyzed were chosen to include EPA Priority One Pollutants, Primary Drinking Water elements, and NPDES pollutants. In addition, the major elements necessary to estimate the fly ash content are included (aluminum, barium, and titaninum). The results of this analysis will provide a comparison of elemental concentrations in dry FGD wastes associated with different coals and different processes. It is anticipated that the bulk of the metals will be contributed by fly ash. The results of these tests will also be compared to the analyses of waste leachate to assess the total fraction of each element that is leachable.

(iii) X-ray diffraction compound identification: This technique will be used to identify specific chemical compounds in the waste samples. The compounds to be identified basically include calcium and sodium salts.

(iv) Moisture content determination: Higher temperatures recommended in ASTM procedures (105°C and 180°C) will remove chemically bound water present in all FGD solids. Therefore, all solids will be dried at 50°C for 4 hours, dissociated for 1 hour and weighed.

(v) Acid and water insolubles: The fractions of each of the waste samples which are insoluble in an acid and a water extraction will be determined. Acid insolubles will be determined, subject to approval by EPRI, using a modified ASTM procedure C-25.

(vi) Leaching tests: The elements analyzed in the leachates will be the same elements analyzed in the solids. Analysis will be done by emission spectrophotometry. Results of the leaching tests can be compared with the total solids analysis to determine the fraction of each element which is leached. The tests will also classify each waste as hazardous or non-hazardous according to the Resource Conservation and Recovery Act.

(vii) Measurement of Strength development: Strength development from compaction and hydration reactions will be determined. Powders will be mixed with water in known proportions, compacted into cylinders, and cured. Unconfined compressive strengths will be determined on cured cylinders according to ASTM-D-1633. Strength development will be related to water-to-solids ratio, to curing time, and to powder composition.

(viii) Radioactivity: Coal fly ashes contain varying amounts of naturally occurring radioactive species. In some cases the level of radioactivity may be high enough to cause these ashes to be classified as hazardous under current regulations. Concentration of the following radioactive species will be measured:

- Radium 226
- Thorium 230
- Thorium 228
- Radon 222
- Lead 214
- Bismuth 214
- Polonium 214

(b) DOE's Grand Forks Energy Technology Center (GFETC) is characterizing the chemical and physical properties of waste material produced by the combustion of low-rank coals. This will include waste from dry FGD systems as well as wet systems and coal fly ash. The waste material will be characterized chemically and physically through the following steps:

- Collection of the waste materials
- Fixation of FGD sludges
- Chemical and physical analysis of all the waste materials (including) FGD sludges before and after fixation)
- Extraction and column leaching of the various waste materials
- Evaluation of current disposal techniques and future disposal requirements
- Assessment of the GFETC column leaching program results

4.3 CURRENT AND PLANNED DISPOSAL METHODS FOR COMMERCIAL UNITS

The studies performed by most dry FGD system vendors to date have not shown any special treatment requirements for disposal of dry FGD wastes. Consequently, the current and planned disposal methods for dry

FGD commercial systems are not much different from the established disposal methods for wet FGD systems. At present there are only two commercial dry FGD systems in operation. Waste from both the Strathmore Paper Company system at Woronco, Massachusetts and the Celanese Fibers Company System at Cumberland, Maryland, is being trucked to landfills.

Tentative waste disposal plans by utilities with contracts for commercial systems range from dry landfill to ponding of wetted solids. Eight of the 10 utilities have reported disposal plans as follows:

1 natural clay-lined landfill
1 PVC-lined landfill
2 wetted transport to landfill
1 landfill with fixation
1 clay-lined ponding of wetted solids
2 unspecified landfills.

4.4 REFERENCES

1. Buschman, John C., et al. Niro Atomizer, Inc. "Disposal of Wastes from Dry SO_2 Removal Processes". Presented at Joint Power Generating Conference, Phoenix, Arizona. October, 1980.

2. Parsons, Edward L., Buell. Telephone conversation with M.E. Kelly, Radian Corporation. January 14, 1981.

3. Stephan, Pat, Battelle-Columbus Laboratories. Telephone conversation with M.E. Kelly, Radian Corporation. January 9, 1981.

4. Stevens, Nicholas J., Research-Cottrell. Telephone conversation with M.E. Kelly, Radian Corporation. January 5, 1981.

5. Radian Corporation. Proposal for EPRI Research Project RP-1870: Characterization of Spray Drying Wastes.

6. Radian Corporation. Proposal for DOE Contract No. DE-AC18-80FC10200; Characterization of Waste Materials from Combustion of Low-Rank Coals.

7. Rhudy, Richard, EPRI. Telephone conversation with M.E. Kelly, Radian Corporation. January 13, 1981.